USER COST CUSTOMIZATION FOR A FLORIDA BRIDGE MANAGEMENT SYSTEM

By

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Dedication, to

my wife,

Consuelo,

and

my three children,

Roberto,

Alessandro

and

Andrea.

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I am extremely grateful to Dr. Najafi the chairman of my committee who has given me his continuous support, guidance, and encouragement throughout my career at the University of Florida. The proposal of the Bridge Management System to Florida Department of Transportation was originally initiated by Dr. Najafi which has provided me with an opportunity to conduct this dissertation work. I am also grateful to Dr. Thompson for his guidance and constant support throughout my career at the University of Florida. A sincere and wholehearted appreciation is extended to my committee members Dr. Shrestha, Dr. Glagola, and Dr. Foti for their wise guidance in the work of this dissertation.

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Bridge Management Systems (BMS) are tools developed to help decision makers to prioritize projects that gives the highest benefit/cost ratio, where benefits are road user cost benefits. They are identified by the savings achieved in <u>not spending</u> travel time (TT) and vehicle operating costs (VOC) doing a detour, and reducing the risk of bridge related accidents. The state of Florida plus 38 states adopted the BMS Pontis to manage their bridge inventory.

The hypothesis of this dissertation is that values benchmarked from other areas are not suitable to replicate the Florida reality. In order to prove this hypothesis a multi-step methodology was used including bridge-related accident cost using data from 11,332 bridge related accidents which occurred in 1996, sensitivity analyses, using 524 bridges under 39 different scenarios, modeled by Pontis-BMS version 3.4. The original user cost default values in Pontis are: \$37,600 for each bridge related accident (C_a); \$0.25 per kilometer for VOC costs (C_v), and \$19.34 per hour for travel time (C_t).

The findings of this research show the need to raise the Pontis-BMS, user cost default value rates to 45.05, 24.0 and 16.6 percent respectively for accident costs, VOC per kilometer costs and travel time values. The new values are \$68,404.39 for C_a; \$0.3138 for C_v, and \$22.55 for C_t.

The Project Attractiveness Index (PAI), measured by the benefit/cost ratio increased 25.96 % with the use of the new user cost parameters. Sensitivity analyses showed that detour per kilometer is the most sensitive parameter, followed by the detour per hour, and finally the average bridge related accident cost parameter. Using the new default values in place of the old ones, deficient bridges that are related with accidents receive a higher prioritization order to be fixed, giving to decision-makers the possibility to reduce bridge accident risk.

CHAPTER 1
INTRODUCTION

The objective of this dissertation is to develop three new users cost default values to be used in a Bridge Management System (BMS) software known as Pontis. The users cost default values are named Travel Time Costs (TTC), Vehicle Operating Costs (VOC), and Average Accident Costs (AAC).

Chapter 1 presents BMS and why Pontis BMS was selected in this research. Chapter 2 presents reasons why it is necessary to develop a new set of user costs default parameters to be used in Pontis, applicable to Florida BMS. The reasons are the framework for the hypothesis set in this dissertation. Chapter 3 is the literature review focusing on the relevant information related to user cost parameters to be used in the Florida BMS model. Chapter 4 presents the Pontis basic concepts, and the models and their interactions used to optimize BMS. Chapter 5 discusses how the user models are used in BMS to quantify, in economic terms, the potential safety and mobility benefits of functional improvement and elimination of deficiencies to bridges. A hypothetical example is offered showing the evaluation of total benefits. Chapter 6 discusses TTC and the methodology used to develop a TTC parameter under BMS. A predictive mathematical model and the generation of a new TTC are presented in this chapter. Chapter seven discusses VOC and the methodology used to develop a VOC parameter. A predictive mathematical model and the generation of a new VOC are presented in this chapter. Chapter 8 presents bridge-related accident costs and the methodology used to

develop a Florida bridge related AAC parameter. A predictive mathematical model and the generation of a new AAC value are presented in this chapter. Chapter 9 presents a sensitivity analysis study comparing the original set of Pontis user cost default values with the new set of user cost default values developed in this research. The results of the sensitivity analysis study confirm or negate the hypothesis in this research. Chapter 10 presents the conclusions and the recommendations derived from this research. The main conclusion is that the developed default user cost values are suitable to Florida BMS to prioritize projects and to allocate funding to improve Florida bridges.

1.1. BMS Development

New York State can be considered the pioneer in BMS studies using main-frame computers. Others states also developed BMS studies. However, the one from North Carolina can be considered the most documented. BMS developments using personal computers started by the middle of the 1980's resulting in the Bridgit and Pontis BMS software. This research focuses on the BMS Pontis software because FDOT uses it. The AASHTO Transportation glossary defines BMS as a system designed to optimize the use of available resources for the inspections, maintenance and replacement of bridges (AASHTO, 1994b).

The United States has by far the largest number of bridges in the world: 600,000 as compared to second-place Germany with 160,000 (National Bridge Inventory NBI, 1998). Considering that most bridges built in the past were designed for a service life of 50 years, this leads one to conclude that bridges constructed before 1960 are at the end of their service life. This also indicates that there will be growing replacement needs for

those structures, and a growing need for deck repair and replacement for the bridge population constructed during the 1960s (Amrhein 1977).

State Highway Agencies (SHA) responsible for managing the nation's bridges must use limited funds as wisely as possible. A Bridge Management System (BMS) can help SHA evaluate current and future conditions, needs, and determine the best mix of maintenance and improvement work on the bridge network over time with and without budget limitations.

According to the American Association of State Highway and Transportation Officials (AASHTO, 1993) the genesis of BMS is linked with the establishment of the National Bridge Inventory (NBI) in the 1970s. The purpose of the NBI was to inform Congress of the status of the nation's bridges, define the magnitude of bridge needs, support national bridge inspection standards and provide for defense information needs. The Federal Government required that every bridge on public roads and larger than 6.30 meters (20 feet) in total length be described in a national database. Legislation (CFR, 1988) also required that bridges be inspected and evaluated at regular intervals not to exceed two years following the National Bridge Inspection Standards (NBIS, 1995). Scholars (Tuner and Richardson, 1994) and practitioners (Shirole et al., 1994) link the pre-genesis of BMS with the Silver Bridge collapse in 1967 between Point Pleasant, West Virginia and Galllipolis, Ohio that killed 46 people (Mair, 1982). This disaster was highly publicized and drew attention to the aging condition of the nation's bridges.

As of November 1995, the United States had over 590,000 bridges, of which about 100,000 of these bridges were built prior to 1935. Nearly 187,504 bridges are classified as structurally deficient or functionally obsolete due to the increase of legal

weight loads and traffic volumes, combined with the effects of weather and chemicals The budget needed to remedy the national bridge deficiencies is projected to be over $ 80 billion or an average cost of over $ 426,000/bridge (BRM, 1995).

The Florida Department of Transportation (FDOT) Bridge Inventory, 1977 Annual Report, shows a total bridge inventory of 11,156 (Amrhein, 1977) bridges and a recent publication shows a sample of 941 bridges in Florida with functional needs at an average projected cost of over $212,000/bridge to overcome these needs (Thompson et al., 1998). The difference of over $200,000/bridge between the average national cost and the average Florida cost to overcome the bridge needs, is mainly due to the degree of uncertainty in the forecasted national value, and the results of an aggressive maintenance program to extend the useful life of Florida bridges, thereby minimizing the need to replace a large number of bridges within a short period of time. However, shortage of funds forced public officials, administrators, and bridge engineers to learn how to manage limited funds as wisely possible.

By the 1980s many states started to address the problem shown by NBI by developing new analytical methods and procedures to allocate funds among different types of problems to overcome the bridge network deficiencies. Wisconsin (Hyman and Hughes, 1983), North Carolina (Niessner, 1979) , Pennsylvania (Krugler,1985), New York (Wade and Larder, 1973), Kansas (Kulkarni et al., 1984), and Indiana (Youngtae and Sinha, 1997) were the pioneers in developing customized Bridge Management Systems (BMS) using mainframe computers. The purpose of a BMS is to combine

management, engineering and economic inputs in to determine the best actions that can be taken on a network over time.

By the middle of the 1980s, many states had independently come to the conclusion that they needed better bridge management tools, and the national efforts began to converge. Two competing projects were formed, one by the Federal Highway Administration (FHWA), and one by the National Cooperative Highway Research Program (NCHRP). The FHWA project began with a series of 49 workshops held around the nation that resulted in the 1992 release of Pontis (Thompson and Shepard, 1994), five years later the 3.2 version of Pontis was released, and by August 1998 the 3.4 version of Pontis was released. A new version of Pontis is expected by the year 2000. The NCHRP conducted a study known as Report 300 (NCHRPR, 1987). From this report, the panel overseeing the project decided to produce a software package which followed the principles outlined in Report 300. This resulted in the 1995 release of Bridgit (Lipkus, 1994).

The main differences between the features of Pontis and Bridgit with respect to analysis, policy and optimization are listed on Table 1. The ability of Pontis to provide analysis at a network level seems to be the main reason why universities and consultants strongly recommend the use of Pontis to SHAs. Both BMS's use the principle of a systematic analysis of expected benefits and costs as prescribed by Executive Order 12893, "Principles for Federal Infrastructure Investments" (F.R., 1994). However, at the national level, 39 states were Pontis subscribers (Pontis, 1998b) as of May 1, 1998, Florida is in the advanced stage of Pontis implementation in their BMS.

Table 1. Comparison of the Main Attributes Between Pontis and Bridgit BMS Models

Attributes	Pontis	Bridgit
Analysis Level	Network Level and Project Level	Project Level
Policy	Policy Optimization	Subjective Policy Choices
Optimization Approach	Top-Down Application of Policies to Project Needs	Botton-up Aggregation to System Wide

1.2.What is BMS in Pontis

BMS is a complex set of formal procedures for analyzing bridge data, which provides information from which to recommend project prioritization and schedules considering budget and policy constraints. The Pontis analytical software is only one part of the minimum BMS requirements. It requires data input generated from the output of the bridge inspection process, the physical inventory, traffic and accident data, cost models, deterioration models, definitions and policies. The software analyzes the data at different levels of analysis and action categories. The output that monetizes the needs is presented into two main categories: Agency Costs and User Costs. Agency costs are the amount of funds required for maintenance and repairs, rehabilitation, and bridge replacement. User Costs are known as the benefits received by the user when a bridge deficiency is removed (NHI, 1996).

The cost side of the BMS (Agency Costs), is accepted almost without controversy. The benefit side of the BMS (User Costs), traditionally, is not considered in the bridge investment decision process. The scarcity of adequate methodology available to evaluate bridge user costs with accuracy, and the lack of a clear understanding of the role of the bridge user costs, are probably the main factors that support this tradition. Although the

user costs generated by bridge deficiencies are not paid or assumed directly by government, the public is both the user and the ultimate owner of the bridge. Thus, the user costs generated by bridge deficiencies as well as the ownership costs associated with bridge maintenance, rehabilitation and replacement should be considered in the decision-making process for bridge improvement. Today's society has a clear understanding of this concept and for this reason, they have a legitimate right to demand from public officials the use of a scientific approach, instead of the political approach, in decisions that involve taxpayers money.

The term user cost in the BMS output means road users "out of pocket" money spent to overcome bridge deficiencies. In the BMS economic analysis it is named user benefits, since the users are saving in vehicle operating costs, travel time costs and accident costs. Federal Legislation (F.R., 1994) demanded a systematic analysis of expected benefits and costs where benefits and costs should be quantified and monetized to the maximum extent possible. SHA (FDOT, 1997) estimates that user costs are ten times larger than agency costs. If this estimate is true, it is envisioned that future refinement in BMS decision making process will challenge the actual status quo of the SHA users.

The theoretical basis for the methodology for economic analysis using user cost was initially presented in the 1960 AASHTO Report, "Road User Benefit Analyses for Highway Investments (AASHTO, 1960)," and updated by the 1977 ASHTO publication, "A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements (AASHTO,1977)" known as the "Red Book." Besides the fact that both publications

present a procedure to develop a methodology to conduct highway user economic analyses for highway improvements, the publications do not address properly the BMS user cost issue. The later presented more clarity for the BMS design development observed in the decade of 1980. The Pontis BMS was the only one that followed the theoretical basis recommended by the "Red Book" as a base to develop the user costs dedicated for BMS. Its basic model of bridge user costs has three components. These are travel time costs (TTC), vehicle operating costs (VOC), and average accident costs (AAC), as shown in Equation 1. The Indiana BMS model and the North Carolina BMS model do not consider all user cost parameters as indicated in Table 2.

$$\text{User Costs} = \text{TTC}+\text{VOC}+\text{AAC} \qquad (1)$$

Table 2. Comparative Types of User Costs in North Carolina, Indiana, and Pontis BMS Models

Types of User Costs	Indiana (Son et al., 1996)		North Carolina (Johnston et al., 1994)		Pontis (Pontis, 1997)	
	Yes	No	Yes	No	Yes	No
Detour costs due to load restrictions	x		x		x	
Detour costs due to vertical clearance	x		x		x	
Travel costs due to load restrictions	x			x	x	
Travel costs due to vertical clearance	x			x	x	
Narrow width	x			x	x*	
Accident costs due to narrow width				x	x	
Accident costs due to vertical clearance				x	x	
Accident costs due to poor alignment				x	x	

*Included in the accident cost mathematical model

The implementation processes for Pontis BMS generally creates a need for the SHAs to re-engineer the active process related to bridges including clear definitions and required integrated actions between all the stakeholders of the process. As mentioned before, users are by definition, the ultimate owners of the bridge, and for this reason the benefit side of the software should always be considered in the decision making process. However, Pontis allows practitioners to modulate the cost weight in the range of 0-100 % during the evaluation of the agency costs. This provision is to conform to the level of certainty that each practitioner or decision-maker has about user costs. The confidence level in dealing with user costs when compared with agency costs is low.

1.3. Focussing on Pontis

Because Pontis is already installed and operational in Florida, research is necessary to improve components of the user cost model, providing a roadmap for the agency to supplement its existing data resources in the future to ensure continued improvement in the effectiveness of the models. This research has the objective to fulfill this need, and will focus on user cost parameters to be used in the Florida Bridge Network (FBN) system, assuming that the agency costs to run BMS software is in good standing.

A recent survey (University of Florida, 1998) was conducted with all 50 states to try to find ongoing studies that might not yet have been published relating to BMS user costs. No such studies were found, which reinforces the need for this research.

CHAPTER 2
PROBLEM STATEMENT

2.1 Problem

The objective of this dissertation is to develop a new set of user cost default parameters (TTC, VOC, and AAC) to be used in Pontis BMS in Florida. The main problem was that the FDOT BMS team during the implementation of PONTIS BMS first recognized that the default user cost values used in Pontis is not applicable to Florida, and for this reason they funded UF to conduct a user cost study (FDOT, 1997).

The second motive that led to pursue this research was framed by the Highway Capacity Manual which states that traffic conditions are a function of the roadway conditions, the environment and the driver behavior (HCM, 1994). In another words, it is not safe to state that user cost parameters developed for bridge network from state A is applicable to the bridge network of state B.

The third motive was the result of the survey between all 50 states, which confirmed the need to develop new BMS user cost parameters. The following sections detail the problem and the justifications to develop a new set of user costs default values for Florida.

2.2 Survey

The Florida Department of Transportation (FDOT) funded the University of Florida (UF) to perform a research study to develop user cost models for the

Department's implementation of AASHTOWare™ Pontis™ . One of the tasks of this research was to conduct a survey of all 50 SHAs to find out how many states are using user cost in their decision making related to their BMS. From 72% overall response, 83.3 % have not undertaken any work to develop user cost model factors for their BMS implementation. Fifty percent (50%) of the respondents have requested additional information on how to formulate and apply the user cost model efficiently, 55.5% are concerned with truck factors related with BMS, 48.2% are concerned with bridge related crashes, 13.8% are concerned with bridge work zone related costs, and 11.1 % are concerned with bridge deck roughness related costs. The results of this survey confirmed the need for this research with the UF research team. Furthermore, according to Wall and Smith (1998) user cost rates, and cost rate assigned to user delay (i.e., the value of time) are by far the most controversial. Gillespie (1998) states that the state-of-the-art calculation of vehicle operating cost is still ill defined, and that the state-of-the-art in estimating accident costs is undergoing rapid change.

2.3 User Cost Need

The use of user costs, as a tool to perform economic evaluations for highway projects, historically was never a popular choice among decision-makers. The need to select user costs as an economic tool in the economic evaluation of transportation projects emerged from increasing public scrutiny or hostility, concerns with the environment, and legal requirements to avoid undesirable effects to the society.

User costs for road users have existed since 1920. However, the user costs parameter for BMS models came into practice in the 1990's, and today it is still being

refined. There is a real need to increase the knowledge about the importance of user cost in the economic evaluation of bridge related investments. Pontis employs user cost models to primarily set priorities, since absolute need is established by the use of level-of-service standards. The FDOT objective is to remove bias on the existing Pontis user cost model. The FDOT desires to develop a new FDOT user cost model applicable to Florida condition.

2.4 Surplus Theory on User Cost

The surplus theory states that bridge improvements bring benefits to the users. In other words, user costs will be decreased if bridges are maintained regularly and properly. Service is defined as the design level of service (LOS) which is considered the basis for an economic engineering analysis. When a bridge develops a deficiency that generates restriction in traffic flow, this disservice generates a user cost increase. Figure 1 shows the consumer surplus for one period. The estimate of the net user benefits of a bridge improvement is represented by the area U_0ABU_1 where a bridge improvement will reduce the user costs that would have been U_0 to U_1, and the traffic volume is expected to increase from the base level V_0 to V_1.

The formula for consumer surplus is $(U_0 - U_1)(V_0 + V_1)/2$, or the difference in user costs times the average traffic volume. This formula can be shown to be the total benefits to new users plus benefits to present users, as follows:

Benefits to present users (area $U_0AC\ U_1$) = $(U_0 - U_1)\ V_0$
Benefits to new users (area ABC) = $(U_0 - U_1)(V_1 - V_0)/2$
Total Benefits = $(U_0 - U_1)\ V_0 + (U_0 - U_1)(V_1 - V_0)/2$
Total Benefits = $(U_0 - U_1)(V_0 + V_1)/2$

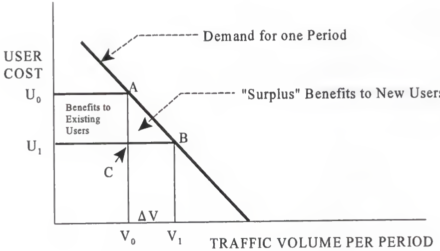


Figure 1. Consumers' Surplus For One Period

User costs at the level U_0 are the costs that the traveling public is experiencing for travel over a bridge that is operating with a volume deficit of ΔV due to bridge deficiencies. These correspond to a low LOS that causes a reduced traffic volume of V_0. User costs at the level U_1 are the costs that bridge users are experiencing after the bridge improvement, where its LOS has been improved, offering an increase in traffic volume corresponding to V_1.

2.5 User Cost Weight Factor

The consumer surplus theory provides adequate support to user costs benefits, and BMS practitioners accept this fact. What they question are the user costs parameters used in the mathematical models developed to evaluate the user costs benefits magnitude. These parameters are specifically the values assigned to travel time costs, vehicle operating costs, and accident costs. The lack of an adequate methodology to develop these cost parameters has led to a large range of user cost values allowing decision makers the possibility of using

vague values which may result in wrongfully prioritizing bridges for maintenance work. This approach was the main reason in lowering the state highway engineer's and project annalist's credibility who relied on vague values of user cost parameters. In order to improve this situation, the BMS AASHTOWare™ Pontis™ allows practitioners to select the weight of user costs benefits according to the credibility assigned by each practitioner for user cost values used. The weight range selection varies from 0 to 100 percent (Pontis 1997a).

This observed level of variability of user costs in BMS could have several plausible justifications. One can be the methodology used in the development of user cost parameters actually used in BMS applications. For example, travel time costs were developed to be used in urban traffic demand forecast studies where the focus is travel time savings, which is totally different from BMS. Vehicle operating costs were developed with emphasis on passenger cars, and BMS requires focus on trucks. Accident costs were developed with emphasis on roadway accidents as a general rule, not focusing on bridge-related accidents.

2.6 Pontis Default Values Origin

There is a need for the use of user cost parameters in Pontis BMS software to perform the benefit cost analysis on each bridge in the network on which a deficiency was located during the inspection. However, Pontis BMS practitioners are not confident about the correctness of the user cost values used as default values: ($19.34/ hr for detour per hour; $.25/Km for detour per kilometer; and an average of $37,600.00 per accident). The Pontis documentation does not outline how these values were developed and from were they came. According to one officer from the FHWA –Bridge Management Division, Mr. Romack, the SHA members that participated in the development of Pontis offered these

values, which are the ones that normally are used at their agencies to evaluate transportation projects. The first version of Pontis used an average accident cost default value of $ 14,000 per accident, which is based on California Department of Transportation (Caltrans) data for 1990 (Pontis 1993). This figure has increased to $17,900 as of 1995, (Pontis 1997a) and to $37,600 as of 1998 Pontis (1998a). The sources from where the VOC and TTC default values came from were not identified.

At the time of the Pontis development, the accuracy of the default values to be used in the Pontis mathematical models was not a main concern of the Pontis developers. Each SHA representative believed that the values developed by their agency were the right ones, and for this reason it was provided a factor, weight (W), in which each practitioner adjusted the default values. Based on this scenario a hypothesis for this research was created.

2.7 Statement of the Hypothesis

Current user costs parameters used as default values in Pontis BMS mathematical models that were benchmarked from other areas are not suitable to evaluate user cost benefits for the Florida bridge network. A specific and customized development of user cost parameters is required for Pontis BMS application, considering local SHA policies.

All mathematical models of the BMS software AASHTOWare™ Pontis™ will be assumed to be appropriate with the exemption of the default values for travel time, vehicle operating costs, and accident costs. The conceptual framework of BMS will be established and used as criteria to evaluate the suitability of the user cost parameter to satisfy the needs of the BMS framework applicable to Florida.

The analysis of the theoretical basis for each parameter is discussed in chapters 6,7,and 8 and the results were used as criteria to establish the development of the user cost

parameter. Each user cost parameter must satisfy BMS needs and the Florida DOT policies while confirming that systematic bias does not exist when using Pontis and making decisions for project selections for replacement or repair work and maintenance. The degree of hierarchy between two available parameter selections will be in the following order: local data --first choice; other state data--second choice; national data--third choice; and international data--fourth choice.

2.8 Validation

The mechanics of the BMS Pontis software are not being questioned in this study. What is being questioned is the quality of the user cost parameters used in the software. Pontis software will be used to validate the quality of the user cost parameters that will come from this investigation. This validation will be performed though a sensitivity analysis where user cost data from this study will be used as new user cost default values for the software. Another sensitivity analysis will be performed using the original user cost default values, and then a comparative study will be performed to define the variability of each set of data.

CHAPTER 3
LITERATURE REVIEW

There is a scarcity of literature sources about BMS, probably due to the fact that BMS is relatively new. The strategy used to collect data relative to BMS was to search the literature under eight main entries in a cross-reference with bridges. The entries used were: Accidents; User Costs; Economic Evaluation; BMS; Inspection; Maintenance and Rehabilitation; Technical Issues; and Others. A form was created to record each entry with the abstract of their contents, the importance for the project, comments and evaluation, and references. During the first six months of the literature review process a total of 72 entries led to 1,571 references. With this literature review start-up it became evident that only two BMS systems are in the process of implementation in the USA, and one in the discussion process. In the world only four BMS systems were located in the phase of discussion (three in Europe and one in South America). Another fact learned was about the quality of the abstracts. In the majority of the abstracts related to BMS, the authors overemphasized the contents of their studies, promising solutions for a common problem in all BMS, that of calculating the user costs in BMS environments. A majority of the BMS related studies only mention that it is possible to evaluate the user costs. However, they do not display how, and do not show the values of user costs parameters.

The abstract summary of each category entry provides an overview of the BMS related issues leading to the selection of the three main issues of this research. The relevant issues found under each category are outlined below.

3.1 Accidents

One of the entries classified as highly relevant was the Blincoe (1996) study, "The Economic Costs of Motor Vehicle Crashes, 1994". This was the first study that presented evidence to support the value of $2,854,500 for a life. For this research, the higher cost values for fatality and injury we can use will contribute more to the economic justification process of the BMS. North Carolina uses the value of $1,500,000 per life for fatality costs, using the "willingness-to-pay" approach. Additionally, the Blincoe study supports the highest cost value for life found in the literature. Blincoe points out that it can be even higher than what he reported.

Kragh, Miller, Reinert (1986), stress the importance of evaluating social costs under the classification of indirect accident costs. Under the two existing approaches to determine accident costs (Human Capital and "Willingness-to-pay"), only the later considers psycho-social costs. It represents 65% of total accident costs. The human capital approach used by the NHTSA considers only 10% of the willingness-to-pay approach. Comparing the numbers used by the National Safety Council (NSC) with the ones used by the NHTSA, it was observed that NSTSA generates cost figures 2.5 times larger than NSC. The authors mentioned above present a cost of $1.3 million per fatality in the "willingness-to-pay" approach which is considered conservative. The Occupational Safety and Health Administration (OSHA) calls for $5 million/life and the Office of Management Budget calls for $1.5 million/life. A compromised value between the two offices is $2,000,000 per life.

A USDOT (1996) publication presents the number of motor vehicle occupants killed and injured in the year 1996. A total of 41,907 people lost their lives in 1996 in motor vehicle crashes, a 2.0% increase from 1995. The fatality rate per 100 million vehicles miles,

was equal to 1.7 with an average of 115 deaths each day (one every 13 minutes). This publication shows the magnitude of the problem. The report points out that trucks account for 12 % of all fatalities, and that accident costs are linked to inadequate truck management in roadway networks. Cerelli (1996) presents the trends in crash fatalities/day for the period 1975-1995 based on National data. Weekends are the period with the highest fatality average, Saturday having the greatest number. Table 3 shows the average number of fatalities per each weekday.

Table 3. Average Number of Traffic Fatalities per Each Weekday--1975-1995

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
150	100	100	100	110	110	190

The author claims that the Saturday fatality rate is very likely related to alcohol use. Another relevant issue related to safety on bridges found in the literature is the issue of "narrow" bridges whose diminished widths may increase the risk of single vehicle collisions with roadside appurtenances such bridge ends, railings or approach guardrails as well as collisions with other vehicles.

Brinkman and Mark (1986) used the bridge and roadway inventory from five states totaling 11,880 bridges and 24,809 accidents during a three-year period. Bridge related accidents were found to be approximately twice as likely to result in a fatality as a typical accident. The same result was found in a North Carolina study. For undivided bridges, the discriminate variables in order of importance are ADT (Average Daily Traffic), roadside distraction, percent shoulder reduction, degree of bridge curvature, curb presence, bridge length, degree of approach curvature and demarcation.

An older investigation made by Turner and Rowan (1982), in a sample of 24,000 accidents occurring between 1972-1979 on Alabama state-route highways, found that roadway accidents rates increase near bridges. One-fourth of the traffic accidents investigated occurred within 0.33 miles of a bridge. The authors observed that many bridge accidents are apparently incompletely investigated, not properly identified, erroneously recorded, misallocated, or ignored due to limited room for identifying information on the accident report prepared by the police.

Zegeer and Council (1995) reports that bridge widening can reduce total bridge crashes by as much 80% depending on the width before and after widening.

Rahim and Johnston (1993) report the accident rate relationship between bridge accidents and roadway accidents for North Carolina, using a sample of 2,000 bridge related accidents. The relationship for fatality, injury type A, injury type B, and injury type C are found to be respectively: 2.0, 1.3, 1.05, and 0.87. The rate 2.0 means that bridge related accidents are twice as severe as other roadway accidents. The predictor equation used by the authors shows low values for the coefficient of multiple determination ($R^2 = 0.33, 0.34$). For this reason it is not recommended to use the equation generated by Rahim and Johnston. They also found that approach roadway alignment is a parameter with no significance for the accident rate. That is contradictory to the findings of Behnam and Laguros (1973), and Brinkman and Mak (1986).

3.2 User Costs

Under this category, the Zaniewski, et al, (1982) study was the second comprehensive study about Vehicle Operating Costs (VOC) found in the literature. This study was financed by the World Bank and was performed in Brazil. The weakness of this study is the transposition of the findings in Brazil to the USA assuming similarities between the roadway networks. However, this study developed tables to update VOC costs against the roadway grade and speed. Currently, the most updated study about VOC is the HERS-- Highway Economic Requirement System (1996), financed by the USDOT-FHWA, where VOC values are developed based on an update of the Zaniewski tables. The evolution observed of VOC studies is as follows.

The genesis of Vehicle Operating Costs (VOC) studies in the USA can be traced back to the period just after the First World War with studies about fuel performance conducted by Agg (1923). In the following years, under Agg management, the research staff at the Iowa State Engineering Station, introduced new parameters in the VOC studies. These included the effect of the roadway geometry on: VOC (Agg and Carter 1928); truck operations (Winfrey 1933); tractive resistance; and road surface types (Paustian 1934).

One of the earliest surveys of VOC was reported by Moyer and Winfrey (1939), who examined the fuel, oil, maintenance and tire costs of rural mail carriers. Moyer and Tesdal (1945) complemented this study with the results from tire wear experiments. In the 1960's, researchers concentrated on the relationships between highway geometry, vehicle performance and costs. Saal (1942) extended his experimental fuel consumption data using survey information, while Claffey (1960) developed models and reported results on speed and fuel experiments incorporating highway and vehicle characteristics.

By the mid-1960s, only fuel consumption could be predicted accurately. Between 1963 and 1969 the National Cooperative Highway Research Program (NCHRP) sponsored Claffey and Associates (1971) to conduct a VOC research which resulted in the classic NCHRP Report 111(Running Costs for Motor Vehicles as Affected by Road Design and Traffic) where the radioisotope technique was used to measure tire wear. This technique was found to be unsatisfactory.

With the growing need for economic appraisal of highway transportation projects in developing countries, the World Bank concluded that the VOC data developed in the USA was not appropriate to be used in these appraisals. Funds were generated to conduct studies in four areas: Brazil, India, Kenya and the Caribbean. The primary data collected in the VOC study performed by Zaniewski, et, al, in Brazil was then used to update a VOC study made in the USA. In June 1982, the Federal Highway Administration published a comprehensive study about VOC performed by Zaniewski et al (1982) with the objective to update the 1971 study of VOC performed by Claffey (1971). This was the last comprehensive study conducted on VOC.

The Zaniewski study was performed with the objective to determine the VOC relationship to roadway characteristics in order to determine the effect of pavement type and condition on these costs. In order to determine the effect of pavement type and condition on selected parameters, and develop an adjustment procedure for these performance parameters as a function of the pavement and condition, five parameters were investigated: VOC, running speed, fuel consumption, vehicle emissions, and accidents. The VOC included consumption of fuel and oil, tire wear, vehicle maintenance and repair, and use-related depreciation. A study made by Harrison et al. (1992) for truck operation costs, using a life

cycle cost approach, found a VOC value of $1.07 per mile for the Pennsylvania I-80 corridor.

In 1996 the Highway Economic Requirement Systems (HERS) sponsored by the USDOT and the Federal Highway Administration published a set of VOCs to be applied to pavement applications. These costs were estimated as a function of the average effective speed, average grade and pavement serviceability rating (PSR), excess operating costs due to speed change cycles and excess operating costs due to curves.

A new approach to evaluate VOC costs was found by Delucchi (1996). The Delucchi study introduced the concept of social cost analysis into VOC costs dividing it into two groups: non-monetary and monetary costs. The author states that costs of travel delay imposed by others (which is the case of a bridge restriction) remain completely unpriced for the responsible motor-vehicle user.

Another source of VOC was the American Truck Association. In 1988 they reported a cost of $1.07 per mile where 79.26 cents/mile represented variable costs (ATA 1990). In 1992, the cost reported per mile was $1.20 (ATA, 1992). In 1996, the cost per mile reported was $1.25 (ATA, 1996). In 1997 the cost per mile reported jumped to $1.92 (ATA-1997). The main reason for the discrepancies in the VOC reported by ATA was due to the lack of methodology to evaluate the VOC. Cost components were included or removed without any justification.

For travel time costs, the most important source found in the literature was traced to the studies by Miller (1996). Almost all relevant work on travel time uses Miller's methodology. In the HERS (1996) study, the value of one-hour travel time by a vehicle was developed using the Miller approach. They are listed on Table 4 using 1993 dollar.

Table 4. Travel Time Cost--Dollar per Hour-Base 1993--Miller Approach

Auto	4-tire truck	6-tire truck	3-4 Axle truck	4-Axle Comb.	5-Axle Comb
$11.22	$12.61	$23.69	$27.7	$30.09	$30.26

Software named MicroBencost was identified as a tool to evaluate travel time on different roadway scenarios. The Tennessee DOT used it to evaluate the travel time value at nine (9) different scenarios in the case of a closure of the Interstate 155 bridge crossing the Mississippi River. The vehicle travel time cost in 1993 dollars per vehicle hour is listed in Table 5. The basic default numbers used in the software are derived from the Zaniewski work.

Table 5. Travel Time Cost-Dollar per Hour-Base 1993--Zaniewski Approach

Auto	4-tire truck	6-tire truck	3-4 Axle truck	4-Axle Comb.	5-Axle Comb
$10.34	11.74	22.11	25.42	28.16	28.33

3.3 Economic Evaluation

A model used in traffic assessment was developed by Texas A&M University named QUEWZ-92. It is more oriented to evaluate queue lines for work zones and the total costs for delay. The default values used for cars and trucks in 1993 dollars are respectively: $12.64 and $23.09 per hour (Krammes et al., 1993).

Farid, et al. (1994) developed a formula to estimate the annual user cost of an existing bridge. This formula uses the proportion of vehicles involved in accidents due to bridge deficiencies and the proportion of vehicles that need to detour, also due to bridge deficiencies. The weakness of this mathematical formula is the assumption made for the proportion of each vehicle type that will detour due to load and vertical clearance

limitations. Also, it is not clear how to find the proportion of vehicles that will be related to an accident.

3.4 BMS

As mentioned before, only the BMS Pontis and Bridgit are being implemented. However, it was observed that new BMS models are under development around the world. Countries like Russia (Johnson et al., 1998), Poland (Vegosz and Wysokowski 1995) and Hungary (Kolozsi 1995) are developing BMS models that do not consider user costs. In Brazil, an Engineering Company named MCN Engenharia Ltda is developing a BMS named SIMGO (NHI-1999).

A study made at North Carolina State University by Chen and Johnston in 1987, resulted in a BMS analysis program which considers owner costs and user costs to determine the optimum improvement action and time for each individual bridge in a system under various levels of service. A sample of 17,000 bridges in North Carolina were analyzed using ADT data from 1974-1984. The coefficients used to measure proportions of vehicles that incur accidents due to deck width, alignment and vertical clearance deficiencies are assumed to be constant. The proportion of vehicles that detoured due to load and vertical clearance is also assumed to be constant. These assumptions are not consistent with the 4.6 % yearly ADT increase observed in the North Carolina Interstate System. The vehicle classification distribution is adjusted using data from six different studies. The truck weight distribution is adjusted based on a study made by the FHWA in 1985 about the bridge structure-loading spectrum. The truck speed at a detour is evaluated by dividing the driver salary and benefits at union scale of $13.35/hr, by the owner-operator driver salary of 0.311/mile, resulting in an average speed of 40mph. This approach is

mathematically correct, however, conceptually wrong once the average speed changes according to the salary variation between the two categories. VOC value for cars are based on the Internal Revenue Service (IRS) allowance of 20 cents per mile plus 15 cents for labor. For trucks the VOC value is derived from the data collected by the United States Department of Agriculture (USDA) at the value of $1.15 per mile.

The BMS study developed by Yongtae and Sinha (1997) uses a new methodology to estimate user costs. It was developed to address the needs of the Indiana DOT. It considers detour costs for load and vertical clearance bridge restrictions, and travel time due to load, vertical clearance and width bridge restrictions. The weakness of this methodology is the absence of the user costs related to bridge related accidents. One of the main features of this work is the calculation of traffic proportion used to evaluate user costs. It has more flexibility than the North Carolina BMS model.

The VOC cost is calculated based on the update of Zaniewski's work, which produces extremely low values. The study has an innovative approach to evaluate user costs due to narrow width.

A brief from the NCHRP that lists all projects in progress, indicates a new BMS model named StratBENCOST which was to be released in 1997. However, this product could not be found in the literature (Lewis 1992a, 1992b). Keating and Turner (1994) report a new BMS software named ALBBRIDGE that is the BMS from North Carolina customized from the Alabama DOT.

3.5 Remaining Relevant Entries

All sources located under the entries Inspection, Maintenance and Rehabilitation, Technical Issues and Others were of no importance to the objective of this research.

CHAPTER 4
PONTIS BMS BASIC CONCEPTS

BMS is an analytical tool that empowers decision-makers with the ability to make effective decisions for optimal use of available resources in the bridge business. This chapter has the objective to discuss the BMS basic components, their capabilities, and their decision management support output to accent the importance of user costs into the system. Shirole et. al. (1994) states that in any BMS, there are only three basic components: data, data analysis, and decision support. They are expanded in Figure 2. The BMS of focus in this dissertation is the AASHTOWare™ Pontis™.

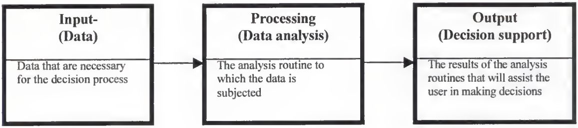


Figure 2. Data Treatment Flowchart

Pontis is the Latin world meaning "pertaining to bridges." According to Thompson (1994), the overall BMS structure involves the input of condition prediction and cost models to the database. The database is then used to optimize preservation and determine improvement strategies. Along with additional supporting data, from the database, these are integrated to form the program. Figure 3 shows this overall BMS structure.

According to AASHTO (1993) the database needs to contain inventory, inspection and appraisal data as well as complete historical information and codes indicating the dates and nature of detailed, special and supplemental inspections. The BMS software needs a capability to edit and update the database as appropriate. The database includes many of the data items in the NBI database, but also needs to include other items, especially a more detailed inventory, and condition data on the elements of each structure.

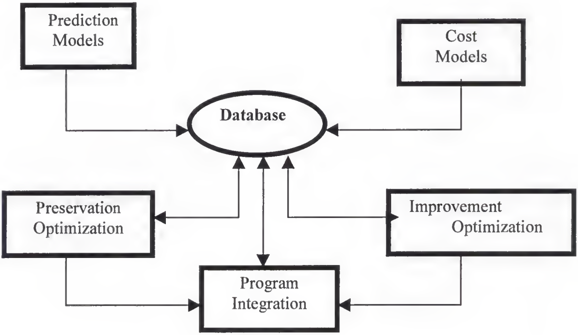


Figure 3. Overall BMS Structure

4.1 Pontis Database

The main objective of the BMS database is to provide identification of needs, accurate economic forecasts, prediction of physical condition, and continuous improvement. The Pontis approach to generating a database is compatible with the modeling operations, and includes: the definition of each bridge by its individual element;

the establishment of particular classification of the condition of a bridge element. The term "feasible action" means "a defined BMS preservation activity unique to an element's material composition and condition state". Preservation activities are referred to as all actions taken to offset the deterioration caused by traffic, weather, or any chemical or physical process.

The selection and definition of structural elements is a central issue in preparing a bridge database for successful modeling. Pontis adopted the AASHTO proposed list of standard elements referred to as Commonly Recognized Elements (CoRe ,1996). There are a total of 98 structural elements described in the CoRe Bridge Inspector's Field Guide. The condition state of each element receives a classification in the range 1 to 4, and 1 to 5 integer scales where 1 indicates excellent. Pontis has about 140 different types of bridge elements defined. Federal funding apportionment to States is still based on sufficiency ratings derived from the NBI Structure and Inventory Appraisal (SI&A) data. The primary NBI data item for prevention of failure is still the condition rating on a scale of 0 to 9, where 9 indicates excellent condition. The NBI requires condition ratings for only three major structural components: deck; superstructure; and substructure. To merge Pontis and NBI data, a standard conversion program, commonly refereed as the NBI translator or BMSNBI, was developed by the University of Colorado (Hearn et al, 1997) to compute NBI ratings from Pontis.

The element listing includes a description, a definition, condition state language, and a unit of measurement for each element. The element descriptions consider material composition and, where applied, the presence of protective systems (NHI, 1996)

Each element is also categorized in one environment. Pontis defines four types of environments to which each element can be exposed: benign, low, moderate and severe. The definition of each environment type is listed on Table 6 (NHI, 1996).

The efficacy of element-level bridge management systems evaluation, such as used in Pontis, has been confirmed by Hearn and Renn (1999) for eight highway bridges in Colorado.

Table 6. Pontis Definition of Bridge Element's Environment

Benign	Environmental factors and operating practices are not likely to significantly change the condition of the element over time or their effects have been mitigated by past non-maintenance actions or the presence of highly effective protection systems. Example: desert bridges
Low	Environmental factors and operating practices do not adversely influence the condition of the element or their effects are substantially lessened by the application of effective protective systems. Example: reinforced concrete bridge in a warm climate
Moderate	Environmental factors and operating practices are considered to be typical for the Agency and any change in the condition of an element is likely to be normal. Example: Reinforced concrete bridge in the north with average use of road salt
Severe	Environmental factors and operating practices contribute to the rapid decline in the condition of an element. Protective systems to negate environmental effects are not in place or are ineffective. Example: bridge in brackish water, bridge exposed to excessive deicing chemicals.

Source: National Highway Institute, 1997- (NHI, 1976)

4.1.1 Needs Identification

The identification of needs is classified in two classes: functional and preservation needs, that are also named as MR&R needs. In order for Pontis to identify functional needs, it requires data on widths and clearances, load capacity, traffic, and accidents. To identify preservation needs, it requires evidence of deterioration, such as the condition to describe the physical symptoms of deterioration which can be visually observed by inspection.

4.1.2 Cost Models

Cost models are related to accurate economic forecasts, economic inputs, including unit costs, user costs, and the transportation service attributes which determine user costs, such as traffic and accident rates.

4.1.3 Prediction Conditions

To predict the physical condition of bridges, the BMS needs deterioration rates, which are developed by making use of all available past inspections as well as expert judgment. In order to distinguish between the effects of deterioration and the effects of maintenance, the BMS needs to know what past maintenance was done on each bridge.

4.1.4 Continuous Improvement

Continuous improvement prediction models can be continuously improved over time if there are methods to compare the predictions with what subsequently actually happened. The cycle between models and outcome is shown in Figure 4. The database structure contains four sets of basic information about each bridge, describing the bridge itself, and each of its elements, roadways and spans or structural units. They are listed on Table 7 (NHI,1996).

4.2 Prediction Models

There are two kinds of models to predict future bridge conditions: deterioration and action effectiveness. Deterioration models predict what will happen to the bridge if no maintenance or improvement is performed. It tells how quickly the bridge element will reach a condition level where some corrective action might be warranted. Action effectiveness models tell how the condition is changed if a maintenance or corrective action is actually performed.

Table 7. Basic Inventory Information for Each Bridge (NHI, 1996)

About the Bridge	About Elements	About Roadways	About Structure Units
Identification • Age/Service • Geometry • Clearances • Condition • Appraisals • Navigation • Load Rating	• Material • Type • Environment • Quantity	• Identification • Traffic • Ruts • Dimensions	• Design • Material

Deterioration models can be divided into two groups according to how they handle uncertainty: Probabilistic (subject to uncertainty) and deterministic (known for certain). Pontis applies the probabilistic Markov Chain process, which means that they divide time into discrete, equal periods; forecast next period condition, without regard to earlier conditions; and perform this prediction by use of transition probabilities among the condition states. The strength of the Markovian models used in BMS is that it is simple to use, (requires low data collection, it is easy to update from historical data, and has the ability to use an inexpensive visual inspection procedure to collect the required data). The weaknesses are that it is not precise and can not model latent properties. Kleywegt and Sinha (1994) state that the developers of Pontis suggested an approach to overcome the Markovian approach weaknesses by using the subjective judgment of bridge maintenance experts to obtain estimates of transition probabilities. As data are collected through regular inspections, these initial estimates are updated and improved. Developers of the BMS software named BRIDGIT (Lipkus, 1994) and Mansino and Pardi (1999) also employ the Markov Chain Process to calculate the transitional rates for each condition state of a bridge element.

4.3 Cost Models

Tuner and Richardson (1994) state that BMS are driven by costs. Everything eventually is compared in terms of costs. Costs are the common denominator in bridge management systems. The degree of difficulty to estimate bridge related cost was compared by Son and Sinha (1994) as the same degree to produce deterioration rate estimates for groups of bridges.

The aim of BMS is to help decision-makers make cost-effective decisions. For this reason cost models are also an important set of inputs to BMS. There are many kinds of cost models, each sensitive to a different set of factors. Pontis uses maintenance, repair and rehabilitation (MR&R) direct costs, functional improvement and replacement direct costs, indirect costs, and user costs.

MR&R costs primarily depend on structural characteristics of the bridge and the extent of deterioration which is to be corrected. They are specific to bridge elements expressed in dollars per physical unit, specific to the type of action and may depend on condition location and element properties (NHI, 1996).

Functional improvement and replacement costs are normally provided by the SHA. Those are the costs to widen or strengthen a bridge. Indirect costs are associated with the decision to perform any work at all on a bridge. They include design, traffic control, land, environmental mitigation, demolition, and administration (NHI, 1996).

User costs measure the effect of substandard bridges on road users. Although the inconvenience to each vehicle is small, the numbers add up quickly. User costs are related to weight limits and clearances in the areas of truck height/weight distributions, detour lengths/times, truck driver labor cost per hour, vehicle operating cost per kilometer, bridge

related accidents, traffic delay costs in work zones, and environmental costs. User cost models require some special inputs of their own. Many agencies maintain these data in their planning departments because they are used for many other purposes. Accident rate estimation is the most difficult because it is necessary to identify the accidents which are specifically associated with bridges.

4.3.1 Preservation Optimization Models

The Pontis preservation model is in reality a comprehensive set of models to optimize the structure preservation policy, to recommend actions, and to set priorities. Figure 5 is a simplified schematic diagram of how data flows in preservation modeling. The main steps of the process are:

Step #1: Development of a probabilistic deterioration model (Pontis, 1997a).

Step #2: Update of the probabilistic deterioration model (Pontis, 1997a).

Step #3: Development of a set of unit costs for preservation actions (Pontis, 1997a).

Step #4: Update of the set of unit costs based on experience (Pontis, 1997).

Step #5: Optimization model that combines the consideration of condition (Pontis, 1997a) change, action effectiveness, and action cost to determine the most cost-effective long-term policies.

The guiding principle of the preservation optimization models is to find the long-term policy for each element in each environment which minimizes the long-term maintenance funding requirements while keeping the element out of risk of failure.

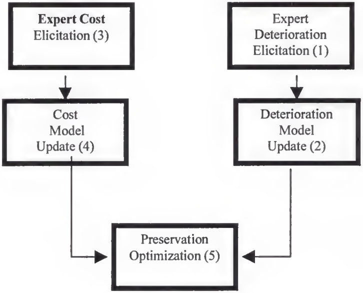
Another important concept of optimization is steady state. Bridges stay in service for a very long time, and the overall objective of providing transportation connectivity

means that there is never a point in the future where network-wide preservation policies might have to be drastically changed or eliminated.

Figure 5. Data Flows in Preservation Modeling

The preservation optimization process is one of the alternative results of the bridge program. It includes the phases of inspection, policies, programming and project.

The inspection objective is to detect conditions threatening the structural integrity.



Past bridge collapses due to failure of fracture-critical members, failure of underwater members, and scour of foundations soils, have attracted attention to these failure modes. There are three basic requirements which BMS policy should meet. They are: experience--the policy and its predicted impacts should be consistent with reasonable expectations of how bridges will deteriorate and how much proposed actions will cost; feasibility--recommended actions should be feasible for the agency to accomplish; sustainability--the

policy should be sustainable over a long period of time, because the bridges will be in service for a long period of time. Automated support for defined objectives, and ways to quantify them, guide policy decisions. There are four network level objectives: minimize agency costs; minimize user costs; maximize service life; and maximize progress toward optimal conditions. There are also constraints: budget and level of service.

With objective quantitative policies and criteria, it becomes possible to generate project lists automatically as a way to approximate quickly the composition of an objective, budget-constrained program. Pontis uses the network level policies and standards to generate projects. A project is a collection of preservation and functional improvement actions on a single bridge. The basic decision criteria is to accomplish as much as possible with the current budget, minimize the long term cost of keeping each bridge in service, minimize inconvenience to road users, and act in a consistent manner across all projects. The focus should be to find an optimal balance and combination of all alternatives.

Preservation policies are developed with the help of a model which specifies action selection rules, unit costs and calculated benefits. An action selection policy, for example, aids in the choice of project level action by specifying the action which gives the lowest long-term costs, based on condition and environment. Network-level unit costs provide an initial rough estimate of project costs as an interim step until a more detailed project cost estimation can be performed. When a network-level policy analysis tool, such as Pontis, calculates life cycle costs, it can compare the annualized long-term cost if the recommended action is taken, to the annualized long term cost if no action is taken. The difference can be expressed as the benefit of the action, and can be allocated to the project on a unit basis.

Functional improvement policies have a similar relationship to the definition of projects. Standards typically determine the type of improvement action to be taken. Design standards are generally higher than level-of-service standards, because a bridge, which is only slightly below design standards, probably would not merit the expense of improving it. In Pontis, a level of service standards is typically determined by an interactive process where the budget requirements of the standard are determined, and then the standard is adjusted so its budget requirements more closely match likely funding availability. Initial cost estimation is typically handled in the same way as with preservation projects, and project benefits are typically expressed as savings in user costs.

According to ASSHTO (1993), preservation actions (MR&R actions) should be evaluated based on their necessity to keep a bridge open and serviceable to users, and a MR&R program should be formulated to minimize the agency cost of maintaining a standard. Improvement actions on the other hand, should be evaluated on the basis of potential user cost savings in travel time, vehicle operating costs and accidents.

Results of the optimization analysis include the long-term percent of each element in each condition state, the long-term annual cost of each action, and the low cost recommended action.

4.3.2 Improvement Optimization Models

The ASSTHO BMS guidelines (ASSHTO, 1993) establish a difference between preservation and improvement actions. Pontis follows the same criteria. Improvement actions considered by the Pontis improvement models include widening, raising, and

strengthening. Functional needs are determined primarily by design and LOS standards. Standards are included for lane and shoulder widths, vertical clearances, and load limits. The original source of level-of-service standards is the June 4, 1991-FHWA Notice of Proposed Rule-Making on level-of-service standards (F.R., 1991). The design standards are based on Caltrans practice, which in turn is based on the AASHTO Geometric Design Policy "Green Book"(AASHTO, 1994b). The bases to perform the decisions in the preservation model are listed in table 8.

Table 8. Bases for the Need and Benefit Calculations on Improvement Projects

Widening Need	Based on comparison of current roadway widths to the width standards set in the Pontis policy matrix
Widening Benefit	Based on estimated reductions in accident costs
Strengthening Need	Based in the structure level operating rating and design load, and LOS standards in the network level policy matrix
Strengthening Benefit	Based on reduced truck traffic detour costs. These have both a time and a distance component.
Raising Need	Based on comparison of current roadway vertical clearance to the clearance standards set in the policy matrix
Raising Benefits	Based on reduced traffic detour costs. These have both a time and a distance component.
Replacement Need	Based on presence of vertical clearance or width deficiencies
Replacement Benefit	Based on reductions in accident and truck detour costs

Reference: Pontis User Manual (Pontis, 1997a)

4.4 Program Integration Model

The integrated project programming model which selects the most cost effective set of structure projects is described by Pontis User's Manual (Pontis, 1997a) in the following terms:

> "The Pontis project programming model performs a simulation of structure condition change and traffic growth for up to a 30-year time horizon, and selects the most cost-effective set of projects which meet the constraints of a user-defined set of budget limits. The procedure integrates the results of the preservation optimization

> and the functional improvement models, developing and evaluating project alternatives, which incorporate both preservation and functional actions. The simulation is designed to develop a set of candidate projects to meet the identified needs, but it will also accommodate a set of projects, which have been manually defined by the user."

This module basically defines and selects a set of projects which optimize expenditures with established budget constraints for a given scenario. The determination of needs changes from year to year over a specific selected planning horizon. The generation of project alternatives includes preservation only, preservation and functional improvement, and replacement.

4.5 Pontis Results

Pontis BMS produces more than 60 reports and it has the capability to generate a customized report. Appendix A shows a list of the reports available from Pontis, covering the areas of inspection, preservation results, network-level programs, project-level programs and historical projects.

From the perspective of user cost models the first point is to define costs and benefits. Agencies use the terms "costs" and "benefits" in many different ways for many different purposes. In BMS, the definitions are chosen so that they accurately reflect what is at stake in bridge management decisions. Seven different types of cost were found in the agency vocabulary. They are direct costs, avoidable costs, budgetary requirements, "full" costs, first costs, life-cycle costs and social costs. Seven different types of "benefits" definitions were found. They are avoided costs, budgetary reductions, social benefits, payback period, internal rate of return, net present value and extended "service life." Some of these terms will be discussed in the following chapters. Pontis adopts for "cost" and "benefits" the following definitions:

Costs are defined as budgetary requirements, but not as additions to the budget. Usually when a cost is incurred, it is treated as a reduction of funds available to other projects. Direct and indirect budgetary first costs are incurred. "Benefits" are defined as avoided costs to the agency and to road users, minus the first costs. Thus they may be referred to as "net benefits". As a result of these definitions, any benefit/cost ratio greater than zero represents an attractive investment. These concepts will be expanded in the following chapters.

CHAPTER 5
PONTIS USER COSTS MATHEMATICAL MODEL

This chapter discusses user cost mathematical models used to quantify the annual benefits resulting from widening, raising, strengthening, replacing, and detouring a deficient bridge, which are evaluated with respect to the user cost default parameters. Florida default parameters that are related to the benefits listed above are also presented. This information is extracted from a FDOT user cost study (Thompson, Soares, Najafi, Choung, 1998). One illustrative example is presented showing the savings in accident costs (SAC), vehicle operating costs (SVOC) and in travel time (STT), using the original Pontis cost default parameters.

5.1.Benefits and User Costs

One of the Pontis requirements is that benefits of functional improvements are assessed in terms of user cost savings (Glolabi et al., 1992). Benefits are the value of taking actions to address the functional improvement needs. Standard functional improvement actions include widening, raising, and replacing a bridge. The benefits of addressing functional improvement needs are calculated by user-modifiable formulas which are based on user cost (travel time, accident) reductions gained from eliminating detours and improving safety (Pontis, 1997a). A functional need is related to the structure's ability to accommodate user demands. Examples of functional needs include the need to increase clearances, increase widths, or raise weight limits in order to serve more traffic and/or improve safety.

5.2 FDOT Default Values Policy

The user cost model is used only for functional improvement and replacement projects. There are 64 data items that are included in the Pontis user cost model. Seventeen of those items are related to bridge data variables, and 47 items are related to mathematical model parameters.

The 47 mathematical model variables resulted from SHA policy. They are defined to input to seven different models: user costs; traffic; widening; raising; strengthening; replacement; and detour. The model parameters are defined by the FDOT. Appendix B presents the widening, raising, replacement, strengthening, detours, and bridge data adopted by the FDOT to be used in Pontis. The Pontis cost matrix that relate to user costs as defined by FDOT policies is shown in Table 9.

Table 9. Cost Matrix Values Adopted by FDOT

Model Variable	**Model**	**Florida Default Value**
Detour cost per hour	detour	$19.34
Detour cost per kilometer	detour	$0.25
Cost per Accident	widening	$14,247*
Weight given to user cost	user cost	100 %

Source : Thompson, Soares, Najafi, Choung, (1998)
* At the time of the report FDOT was using this value. Current value is $37,600

Bridge data variables are bridge functional class, detour distance, detour speed, roadway functional class, roadway speed, truck fraction, vertical clearance, operating rating, future volume, future volume year, traffic volume, traffic volume year, bridge length, approach alignment rating, approach road width, number of lanes, and roadway width. The values adopted by FDOT are listed in Appendix B, Table B6.

A user cost model is fed with the weight given to user cost that is expressed in a percent index. In Florida's case it is 100%. The traffic model is fed with the default traffic growth period, normally 30 years. The widening model is fed with cost per accident, high approach alignment rating, low approach alignment rating, approach width factor, design lane width, design shoulder width, short bridge threshold and two regression constants. The raising model is fed with height detour default, and 10 different height detour points. The strengthening model is fed with four weight detour points. The replacement model is fed with five height eligibility points. The detour model is fed with detour cost per hour, detour cost per kilometer, detour speed factor, default truck percent and 12 levels of default road speed.

There are three different tables where these data values are located. They are: cost matrix; policy matrix; and improvement model tables.

The Cost matrix items include agency functional improvement unit costs, user detour and accident costs, agency costs for special improvements such as seismic retrofit and scour protection, and associated agency and user benefits for making special improvements. For this dissertation, the focus is on the four user cost models defined as follows:

<u>Detour per hour</u>--user costs per hour of additional travel time incurred by vehicles that would normally use a structure but cannot due to clearance or load restrictions. This is used to calculate user cost reductions associated with raising or strengthening a structure (Pontis 1997a).

<u>Detour per kilometer</u>–user costs per kilometer of additional travel distance incurred by vehicles that would normally use a structure but cannot due to clearance or load

restrictions. This is used to calculate user costs reductions associated with raising or strengthening a structure (Pontis 1997a).

Average per accident--the user costs per accident. This is used to calculate the accident reduction benefits of widening or replacing a deficient structure (Pontis 1997a).

Weight--determines the relative impact (a percent) of user costs to actual costs in the benefit-cost calculations. If the user cost weight is 100, user costs are treated on a par with agency costs. If the user cost weight is 50, user costs would be cut in half (Pontis 1997a).

The policy matrix contains standards when different types of improvement actions should be applied. These standards can vary for different combinations of ADT class, functional class, structure funding responsibility, and NHS status. The improvement model parameter table contains improvement benefit model parameters defined for each improvement matrix in the programming module.

5.3 User Cost Models

When a deficient NBI approach alignment or roadway width exists on a bridge, road users are theoretically subjected to a higher accident risk. To evaluate a functional improvement or replacement which corrects the deficiency, the user cost model predicts a reduction in accident risk which then is multiplied by an accident cost to yield a user cost saving. When a bridge has a substandard vertical clearance or load capacity certain trucks are unable to go on or under the bridge, and must detour, thus incurring higher labor costs and vehicle operating costs. The user cost model estimates the volume of detoured traffic and the resulting user costs which would be avoided if the deficiency were corrected. The total user benefit of the functional needs in a project is therefore:

User benefit $$B_r = W_c / 100 \times V_{ry} (BW_r + BR_r + BS_r) \qquad (5)$$

Where:

W_c is the weight given to user cost benefits, in percent (Pontis cost matrix)

V_{ry} is the forecasted average daily traffic volume for the program year being analyzed.

BW_r is the annual benefit of widening per unit average daily traffic (calculated below)

BR_r is the annual benefit of raising per unit average daily traffic (calculated below)

BS_r is the annual benefit of strengthening per unit average daily traffic (calculated below)

In the notation for all equations, subscripts indicate either the level of resolution of the variable, or the entity which the variable describes. These are defined as follows:

$_b$ indicates a bridge attribute (corresponds to bridge or inspection event table)
$_r$ indicates a roadway attribute (corresponds a roadway table)
$_c$ indicates a cost matrix parameter (linked to the bridge table)
$_p$ indicates a policy matrix parameter (linked to the bridge table)
$_y$ indicates a program year within the planning horizon (Thompson et al. 1998).

Variables without a subscript are systemwide parameters. Approach alignment rating is the only attribute of this type. When a bridge-level attribute is taken from the inspection event table, it is taken from the most recent inspection for the bridge.

5.4 Benefit of Widening

Pontis estimates the user benefit of widening as the savings in accident costs. The method for estimating accident user costs in Pontis is derived from the North Carolina BMS using the following formula:

Benefit of widening $$BW_r = CA_c\,(R_r - R'_r) \qquad (6)$$

Where:

CA_c is the average cost per accident (Pontis cost matrix)

R_r is an estimate of the current annual accident risk per vehicle (calculated below)

R'_r is an estimate of the current annual accident risk per vehicle after improvement (calculated below) (Thompson et al. 1998).

This result is calculated only for roadways on a bridge. It is zero for roadways under a bridge. It is also set to zero if $R_r < R'_r$. The parameters R and R' can, in principle, be estimated from actual accident studies. However, no such studies were found in the literature or from the questionnaire survey. The North Carolina system offers an approximate way to estimate R based on bridge attributes as follows:

Current accident risk:

$$R_r = 365 \times 200 \times (3.2808W_r)^{-6.5} [1 + 0.5 (9-A_b) / 7] \qquad (7)$$

Where:

- W_r is the roadway width (curb to curb) in meters (Pontis roadway table, NBI item 51)
- A_b is the approach alignment rating (typically 2 to9, Pontis inspection event table NBI item 72)

If the approach alignment rating is missing, it is taken as zero. It would be more appropriate to take it as nine so it does not add to the accident risk. If roadway width is less then zero, it is treated as zero. Some of the numeric constants in this formula are user-modifiable in Pontis in the improvement model parameter table. They are defined as follows:

365 is the number of days in a year
200 is a regression constant
3.28084 is the constant Pontis uses to convert from meters to feet
6.5 is regression constant
0.5 is a model specification constant
9 is the highest approach alignment rating
7 is the range of allowed approach alignment ratings (Thompson et al. 1998).

The 200 and 6.5 are regression constants derived from the North Carolina study, so they should be modified only if another statistical analysis of accident data is conducted. The 0.5 constant arose because of the practice in North Carolina of assigning only even numbers for approach alignment ratings. It is not important for the model framework, but

must be used with North Carolina regression constants. The final two constants are artifacts of the NBI approach alignment scale, which range from 2 to 9.

The formula for accident risk after improvement is similar to (7), but depends on the width of the improved roadway.

Improved accident risk:

$$R'_r = 365 \times 200 \times (3.2808W'_r)^{-6.5} [1 + 0.5 (9-A_b) / 7] \qquad (8)$$

Where:

W'_r is the roadway width (curb to curb) in meters (Pontis roadway table, NBI item 51)
A_b is the approach alignment rating (typically 2-9, Pontis inspection event table NBI item 72) (Thompson et al. 1998).

5.5 Benefits of Raising

Pontis calculates the vehicle operating cost and travel time cost associated with traffic on a detour route, and assumes that this entire cost is saved if a functional improvement is made. Only trucks are assumed to be affected. Raising is considered only for roadways under the structure.

Benefit of raising is: $BR_r = 365 \times DC_r \times PT_r / 100 \times PH_r /100$ (9)

Where:

DC_r is the detour cost per truck for this roadway (calculated below)
PT_r is the percentage of the traffic stream occupied by trucks (Pontis roadway table, NBI item 109)
PH_r is the percentage of trucks detoured by the bridge.

If the truck percentage is missing or zero, it is given the value of the improvement model parameter default truck percent whose default value is 5 percent (Thompson et al. 1998).

5.6 Benefit of Strengthening

Pontis calculates the vehicle operating costs and travel time costs associated with traffic on a detour route, and assumes that this entire cost is saved if a functional improvement is undertaken. Only trucks are assumed to be affected. Strengthening is considered only for roadways on top of a structure.

Benefit of strengthening is: $BS_r = 365 \times DC_r \times PT_r / 100 \times PW_b / 100$ (10)

Where,

DC_r is the detour cost per truck for this roadway (calculated below)
PT_r is the percentage of the traffic stream occupied by trucks (Pontis roadway table, NBI item 109)
PW_b is the percentage of trucks detoured by the bridge

If the truck percentage is missing or zero, it is given the value of the improvement model parameter default truck percent, whose default value is 5 percent (Thompson et al. 1998).

It is possible that some fraction of trucks exceeds the operating rating, but ignores any posted signs. Also, many states post bridges at levels different from the operating rating. The model makes assumptions about these factors since it describes only the percentage of trucks which are actually detoured at each operational rating level.

5.7 Benefits of Replacement

The user costs model for replacement benefits is very similar to the combined effect of all of the separate functional improvements. An analysis of the source code reveals just a few differences as discussed in this section. When a bridge is replaced, Pontis recognizes the benefits of widening for all roadways on and under the bridge. All roadways are assumed to have the approach alignment rating of the bridge before the project, and all are assumed to have an approach alignment rating of 9 after the project.

Pontis assumes that bridge replacement eliminates all operational rating deficiencies. As a result, the project benefit includes the benefit of strengthening, calculated in the same way as described above in equation (10).

The replacement benefit model for height- related detours in Pontis is formulated to allow for the possibility that, when both height and weight restrictions exist, certain trucks may be affected by both restrictions.

Replacement height benefit = BR_r

$$BR_r = 365 \times DC_r \times PT_r / 100 \times [(1-PW_b/100) \times PG_b/100 \times PH_r/100] \qquad (11)$$

Where:

- DC_r is the detour cost per truck for this roadway (calculated below)
- PT_r is the percentage of the traffic stream occupied by trucks (Pontis roadway table, NBI item 109)
- PW_b is the percentage of trucks which are detoured by the bridge due to weight (Pontis roadway table, NBI item 109)
- PG_b is the percentage of those trucks not detoured by the weight limit, which are potentially subjected to height restrictions.

There is a subtle logical inconsistency in the use of PH_r in the raising and replacement models. In the raising model, PH_r is the percentage of the entire truck traffic stream which is detoured since the percentage detoured by weight restrictions is zero. In the replacement model, on the other hand, PH_r is the percentage of only the lighter-weight duals and tractor-trailers. The $(1-PW_b)$ term restricts PH_r to lighter-weight vehicles, and the PG_b term restricts PH_r to only duals and tractor-trailers (Thompson et al. 1998).

Part of this inconsistency can be removed by setting all the percentages in the PG_b model to 100 so the definition of PH_r, is not limited to duals and tractor-trailers. There is no easy way, however, to remove the effect of $(1-PW_b)$ (Thompson et al. 1998). Considering the Pontis user community as a whole, it would be worthwhile to consider eliminating the PG_b factor and simplifying the definition of PH_r to conform to its usage in the strengthening

model. This could cause some minor double counting of benefits in cases where both clearance and weight restrictions exist on the roadway on top of the bridge, but the number of cases where this is a problem is likely to be small in most states. The benefit of the change would be to make the user cost model smaller, more consistent, and more understandable (Thompson et al. 1998).

5.8 Detour Cost

Each time a truck is detoured, it experiences vehicle operating costs associated with the added detour distance and travel time costs associated with the added detour time. Pontis uses a model of these factors for raising, strengthening, and replacement.

Detour cost per truck $$DC_r = CV_c \times D_r + CT_c \times (D_r / DS_r) \qquad (12)$$

Where:

- CV_c is the average vehicle operating costs per km of detour (Pontis cost matrix)
- CT_c is the average travel time cost per hour of detour (Pontis cost matrix)
- D_r is the detour distance for the roadway in km (pontis roadway table, NBI item 19)
- DS_r is the speed on the detour route, kph, (Ponts roadway table)

Since detour speed is not in the NBI data item, many SHA lack this information. When missing, Pontis estimates the detour speed from the roadway speed (Pontis roadway table) using the improvement model parameter DetspeedFactor. The default value of this factor is 80 percent. Since roadway speed is not in the NBI item, Pontis has a set of default speed values, DefaultRoadspeed FCnn, where nn is the roadway functional class in the improvement model parameters table. Since these defaults are very rough, it is better to collect the actual detour speed or at least the bridge roadway speed, if possible (Thompson et al. 1998).

5.9 Application Example

To clarify how the Pontis user cost mathematical model is integrated into the BMS, one example of one deficient bridge is presented. This example is an adaptation of the Blundell (1997) technical notes for a two lane concrete arch bridge.

One two lane reinforced concrete arch bridge has a deficiency that forces 46% of the truck traffic to detour 38.6 Km. The actual Average Daily Traffic (ADT) is 7,166 and the percent trucks composition is 14%. The BMS analysis result indicates a need to spend $ 1, 850,000 to replace the bridge as the best option to overcome the bridge deficiency. What is the benefit cost ratio for this action assuming the use of the Pontis default values for user costs?

5.9.1 Savings in Accident Cost (SAC)

$$SAC = 365 \times V (R - R') C_a \qquad (13)$$

Where,

V= 7,166 (Average Daily Traffic)
C_a = 37,600 (Average Accident Costs)
R= 0.000035 (current annual accident risk)
R'= 0.0000028 (Current annual accident risk after improvement), explained below

The values for the current accident risk for the current year is R= 0.000035 (this value can be taken from project simulation log files for this bridge). The after improvement widening accident risk is listed by Pontis as R'= 0.0000028 (this value is evaluated by the BMS using the new values of the roadway width Wr, and the new approach alignment rate, A_b).

The difference between the two accident rates is the reduction in accidents.

$$R - R' = 0.000032$$

Since the values of R are adjusted for year, the total SAC will be:

$SAC = 7{,}166 \times 0.000032 \times 37{,}600$

$SAC = \$\ 8{,}622$

5.9.2 Savings in Vehicle Operating Costs (SVOV)

$$SVOC = 365 \times V_D \times C_v \times D \qquad (14)$$

Where,

$V_D = 7{,}166 \times 0.14 \times 0.46 = 461$ (trucks detoured per day)
$C_V = 0.25$ (average vehicle operating costs per kilometer)
$D = 38.62$ (detour distance in kilometers)

The percent of trucks detoured is determined by the user settings in the improvement module. For this particular bridge the percent of trucks detoured was 46% (0.46). The equipment unit cost (Vehicle Operating Costs to overcome the detour length) is: 38.62 x 0.25 = \$9.66/truck.

The number of trucks detoured per year is then trucks detoured per day times 365 days: 461 x 365 = 168,265 trucks detoured per year. Then saving in Vehicle Operating Costs will be:

$SVOC = 365 \times 461 \times 0.25 \times 38.62$

$SVOC = \$1,\ 623{,}757$

5.9.3 Savings in Travel Time Costs (STTC)

$$STTC = 365 \times V_D \times C_t \times D/S \qquad (15)$$

Where,

$V_D = 461$ (number of trucks detoured per day)
$C_t = 19.34$ (average travel time cost per hour of detour)
$D = 38.62$ (detour distance in kilometers)
$S = 70.24$ (speed on the detour route, km/hr) explained below

This step is to include the labor cost for the drivers making the detour. The labor cost is the detour distance divided by the detour speed (in this case Pontis uses as a default value of 80% of the posted road speed, that is 70.24 Km/hr) times the cost of labor per hour. Detour length (38.62 Km)/ detour road speed (70.24 Km/hr) * $19.34/hr labor cost = $10.62/truck. Then the labor unit cost per truck is $10.62/truck. The resulted STTC is:

STTC= 365 x 461 x 19.34 x 38.62/70.24

STTC= $1,789,279

5.9.4 Total User Cost Benefits (UCB)

UCB = SAC + SVOC + STTC (16)

UCB = 8,622 + 1,623,757 +1,789,279

UBC = 3,421,658

5.9.5 Benefit Cost Ratio

Total User Cost benefits/ Agency Costs

3,421,658 / 1,850,000 = 1.85

The BMS follows this methodology for all deficient bridges found in the network, and then ranks all the benefit cost ratios. The bridge that receives the highest benefit cost ratio generates the highest savings for the user when its deficiency is fixed. Assuming that the bridge from the example is ranked in third place in one hypothetical bridge network means that it will receive priority number 3 in the budget allocation process if the SHA decides to use the road users benefit approach.

The main point in this example is that detoured trucks are responsible for 99.75% of the total user cost benefit. That is, 7.6 % of the ADT volume is charged a total of $3,413,036.00 per year for not using the bridge. This represents an additional expense of $20.28 for each truck.

The penalty of $20.28 ($9.66/truck as equipment cost + $10.62/truck for labor cost) paid for each truck for not using the bridge facility is directly related to the detour length, the detour road speed, the VOC selected, and the travel time selected. The total detouring cost is directly related to the number of trucks detoured each year at the bridge.

The lost savings of $ 0.35 cents incurred for each vehicle that uses the bridge is related to the current ADT , the current accident risk rate, and the future accident risk rate after improvement. Each accident rate is related to roadway width, the approach alignment rating , and the average cost per accident.

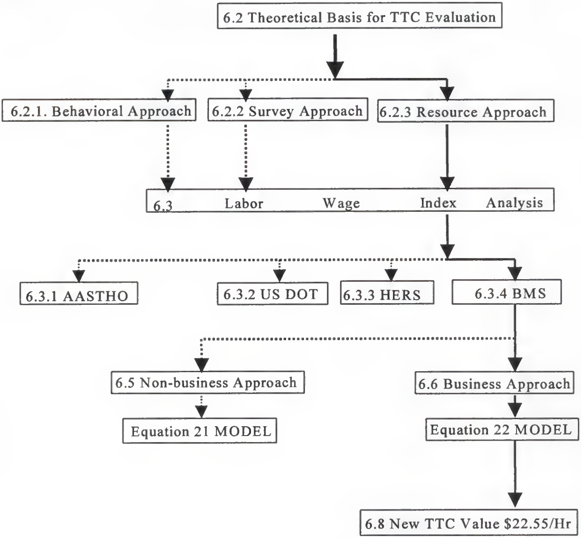
From the 10 inputs data used in the evaluation of user costs, only three are supplied by the NBI source. Different offices in the SHA organization are responsible for generating the seven remaining data input. Maintenance, inspection, safety, law enforcement, engineering and administration offices are normally those involved in data generation for BMS user costs. Four parameters related to policy decisions and one related to law enforcement present the most difficulty in the process of selecting the correct ones. They are the average costs per accident, the average vehicle operating costs, the average travel time costs , the speed in the detour costs, and the proportion of trucks detoured. The implications involved in selecting each one of these parameters will be discussed in the next three chapters.

CHAPTER 6
TRAVEL TIME COSTS FOR BMS

The Travel Time Cost (TTC) developed by this research is $22.55/hour. This chapter describes how this value is developed, the theoretical basis to support its development, and why TTC values benchmarked from other places are not useful for BMS applications in Florida. The structure of this chapter is displayed in Figure 6 where the solid line represents the critical path used to develop the new TTC value, and the dashed line represents reasons why TTC benchmarked from other areas are not suitable for BMS in Florida.

6.1 Background

The value of travel time savings is usually considered by transportation analysts as the most important category of benefits for major highway investments. According to Strand (1993), for the average road project, 70 to 80 percent or more of the total benefits are attributed to the time savings of the project. The way in which time is converted into money is becoming more and more decisive in the calculations to profitability and feasibility of road projects. Depending on the approach used to monetize travel time, one can make a project profitable or unprofitable. Chui and McFarland (1986) state that before 1965, the estimated value of time was based more in intuition and non-behavioral estimates than on a reliable, theoretical model. However, there are several conceptual problems in the evaluation of time; pertinent questions about research issues and bottlenecks related to a credible, practical application of time utilization theories. These issues can turn the use of



Figures 6. Flow Chart for BMS TTC Development

time both meaningless and misleading.

There is a fundamental conceptual difference between the value of travel time for transportation planning and for BMS applications. For the former , drivers are offered several alternatives to choose from on how to move from point A to point B. Road users have the freedom to select the mode, the route, and also how much they are willing to pay for time savings and better driving conditions. On the other hand, for BMS applications the drivers do not have the freedom to select the mode or the route to move from point A to point B, if point A and point B are connected by a bridge. If the bridge is closed or posted, it is mandatory to remain in the same mode and take the bridge detour that has a specific length and characteristic. In summary, planners are interested in knowing what costs an individual is willing to pay in order to save one unit of trip time. With BMS applications, the BMS practitioner is interested in evaluating what costs an individual is forced to pay in order to overcome the extra time incurred in the journey. In the first case, the focus is in travel time savings, and in the second case, the focus is in travel time costs that will be considered as savings once the bridge deficiency is removed.

6.2 Theoretical Basis for Travel Time Evaluation

One major area of application of the macroeconomic approach to the evaluation of travel time lies in the appraisal of improvements in transportation systems. The problem consists essentially of an efficient allocation of resources in the economy, and how time in transport is applied in benefit cost analyses. IF the principle of the welfare theory is used (Bruzelius, 1978; Serpa,1971;), that is, on the individual maximization of benefits, the marginal value of time is the one the consumer is willing to pay for a marginal reduction in travel time. According to Strand (1993) this theory has been severely questioned, mainly by

the existing imbalance between theoretical and empirical calibration (Heggie, 1983), and the way small savings and aggregate problems are treated.

Alternatively, a conceptually identical approach is used to evaluate the economic losses due to unproductive travel time which is addressed in economic theory as opportunity cost. For one category of time consuming human activity, one can establish a value based on the marketing mechanism. A market for labor exists so that the time saving in trips undertaken during working time (on-the-clock trips) can be assigned a value related either to the wage rate or overhead costs. According to Miller (1996), on-the- clock trips have values equal to the wage rate, plus fringe benefits and vehicle/inventory costs.

Behavioral models give the value of time from the perspective of the person whose behavior is being modeled. Thus, models estimated from decisions made by travelers give the value of time saved to the traveler. Models estimated from decisions made by travelers' employers give the value of time to the employers (Morrison, 1996). Because of this, the results from behavioral models are useful when predicting travel demand. However, because of taxes, among other things, these values will most likely diverge from the "resource" values appropriate for use in cost benefit analysis. The following are the description of each of these approaches.

6.2.1 Behavioral Approach

The behavioral approach is an extension of conventional consumer theory that illustrates why time in general and travel time, in particular, is valuable. At its core is the tradeoff between time and money.

The state-of-the-art behavioral models indicated at least five approaches for estimating the value of time. They are identified mainly by the data collected on the choices that the sample of travelers make, e. g., modal choice model (McFadden and Reid 1975,

Ben-Akiva 1973, Charles River Associates 1972, Lave 1968, Lisco 1967, Becker 1965, Morhring 1960), route choice model (Guttman 1975, Thomas and Thompson 1970, Claffey et al. 1961), speed choice model (Chui & McFarland 1986, Winston & Associates 1987), usage of safety belt (Blomquist et al. 1996), and housing price approach (Nelson 1977, Wabe 1976).

6.2.2 Survey Approach

According to Miller (1996) the survey approach is the most effective way to evaluate the travel time value. He suggests that surveys should be done offering each respondent just one or two randomly generated choices per question, with the values implicit in the choices. Another alternative is to find an unbiased starting point then to let the respondents choose a value from a menu that uniformly covers the entire response range.

6.2.3 Resource Approach

The resource approach is used to place value on business travel time for project appraisal. In its simplest form, travel time savings are valued according to the "resources" that are saved, i.e., the work time for "labor", and vehicle and equipment time for "capital" (Hensher 1976).

6.3 Percent Wage Index Analysis

Value time estimate modelers use wages as a reference to monetize travel time. For business travel time they use wages plus fringe benefits. According to Miller (1996), the theoretical basis for the result that the value of work time (to society) is equal to the gross wage plus fringes, is based on the assumption that the labor market and the output market are competitive, that firms are able to substitute capital for labor, that there are no positive or negative externalities in production, and that firms maximize profits. Miller (1996)

considers that this practice provides an automatic adjustment for inflation and facilitates comparison across different currencies and cost of living. However, he questions the validity of the theoretical foundation to support the use of wage to express value of time.

Miller (1996), after analyzing over 30 travel time studies recommends the use of conservative estimates due to a poor fix on the value of travel time. According to him, for project evaluation purposes, a value of travel time of 55% of the wage rate is recommended for drivers with an uncertainty range from 50% to 75%. A value of 40% of the wage is recommended for car and public transport passengers, and a value of 100% of the wage rate, plus fringe benefits and vehicle/inventory costs is recommended for on-the-clock travel.

As can be seen, there is a consensus about the percent wage index to be used in the evaluation of travel time for business. However, for non-business travel there is no consensus. This is a direct reflection of the contribution level provided by the behavior models at the present stage in evaluating travel time. In fact, according to Miller (1996), analysis of highway investments should use travel time values from route choice or speed choice models, and not from modal choice models. The weakness of mode of choice models is that they underestimate the value of personal vehicle travel time savings, comfort, convenience and privacy while ignoring capital investments in a private passenger vehicle. This observation confirms the critics of Hensher (1976) and Gronal (1976) in the use of modal choice models for a wide range of decision variables.

The Texas Transportation Institute (TTI 1993) pointed to concerns raised about the validity of the assumptions made in the speed choice model, which assumes a driver's knowledge of the relation of driving costs to driving speeds.

For a BMS application the route choice has a relatively low importance, because it deals with the choice of routes (often a toll road vs. a parallel non-toll road) and in reality

under the BMS scenario there is no route selection. There is only the detour route prescribed in the NBI item 19 related to each bridge which is fed into the BMS mathematical models. These values do not change; consequently there is no choice involved.

6.3.1 TTC Under AASHTO Methodology

The traditional approach used for analysis of transportation investments is based in the AASHTO 1977 Manual on User Benefit Analysis of Highway and Bus-Transit Improvements. This manual is an extension and replacement of the 1960 AASHTO report, Road User Benefit Analyses for Highway Improvements (AASHTO 1960), and the National Cooperative Highway Research Program Report 133 (NCHRP 1972). Kinboco and Henion (1981) critically evaluated the AASHTO 1977 report a few years after it was published. However, travel time was not evaluated.

6.3.2 TTC Under USDOT Methodology

In 1997, the Office of the Secretary of Transportation (OST) released a memorandum intended to provide DOT staff with the best current available procedures and empirical estimates for calculating the value of time. The focus was on transportation investments, not on BMS. This memorandum recommended the use of nationwide statistics for income/wage rates of the traveling population, using 100 percent of the wage (plus fringe benefits) for all local and intercity business travel, including travel by truck drivers. This equals 50% of the wages for all local personal travel and 70% of the wages for all intercity personal travel (OST, 1997).

6.3.3 TTC Under HERS Methodology

In 1999, the FHWA received the latest version of the HERS (Highway Economic Requirement System) model, which is the result of DOT's efforts to better examine costs, benefits and national implications associated with highway investment options. The

approach used to estimate the travel time value is to apply a value of 100% of the wage rate, plus fringe benefits and vehicle/inventory costs for on-the-job travel, and 60 % of the wage rate exclusive of fringe benefits for other trips (HERS, 1999).

6.3.4 TTC Under BMS Methodology

When a bridge has a deficiency, and this deficiency demands load and height restrictions in the traffic flow, the SHA is faced with two traffic management alternatives: post the bridge and divert a proportion of the traffic to a detour route; or close the bridge and divert 100% of the traffic to a detour route. If the bridge is posted it is assumed that only heavy vehicles (trucks) are diverted.

For BMS objectives, trucks and buses are always treated as being on business trips and the rest of the traffic flow is treated as non-business trips. This assumption generates some bias by ignoring the fact that besides trucks and buses, no other vehicles are engaged in business trips. However, this assumption is adopted due to the lack of data about the composition of business trips existing in the traffic stream. Business trips, also known as on-the-clock trips, have travel time valued on the basis of savings to the employers as discussed before. The savings include wages, fringe benefits, vehicle costs and inventory costs (Miller 1996, HERS 1999). This approach, which includes vehicle costs and inventory costs in the composition of the travel time estimation is not shared by the Canadian Department of Transportation (Culley and Donkor, 1993). For travel time savings for business travel, the Canadians use the approach of "equivalent hourly wage rate" that is calculated dividing the average annual individual earnings by 2,101 hours (52 weeks of work per year at an average of 40.4 hours of work per week). On top of this "equivalent hourly wage rate" is added 19.5% for employee fringe benefits, plus 10% for unreported overtime, plus 14.0% for fringe benefits. As an example a typical "equivalent hourly wage

rate" in 1990 was \$16.39 resulting in a final value of \$24.01 due to the benefits included (HERS, 1999).

The rationale to include vehicle costs and inventory costs is the following: For vehicle costs, capital invested is depreciated for the lifetime of the vehicle assuming a certain salvage value at the end of the life. The resulting average vehicle cost per year is then divided by a number of vehicle working hours in service per year per vehicle category. The weakness of this assumption is that the traffic composition will be treated as having only vehicles aged to the limit of the selected depreciation time. For example HERS assumes a five-year life for autos and four-tire trucks. That is, if in the traffic composition there is a vehicle older than five years, it is treated as a newer vehicle, inflating the depreciation value of the traffic composition. Data from the 1995 National Transportation Survey indicates that the average age by vehicle type has been increased since 1977. The 1995 average age for cars and trucks were 8.24 and 14.93 years respectively. These numbers show that if one uses the HERS approach of five- years life for vehicles to determine their hour value, one is attributing, to a proportion of old vehicles, the value of a newer vehicle. The same survey discloses that for 1995 only 37.7 percent of all vehicles are in the 0 to 5 years age range.

For inventory costs the rationale is to select one discount rate and multiply its hourly value by the average value of the truck cargo. The problem here is knowing what type of cargo each truck is carrying. HERS assumes that 35% of all combination trucks carry low value natural resources and agricultural products, and the remaining 65% of trucks carry manufactured products, including goods of medium to high value, processed foods, building materials and paper products. The weakness of this approach is due to the assumptions made. It basically divides the truck population in two groups in which one will be sensitive

to the inventory cost and the other group will not. Using the values published by the 1977 transportation census, we have a median value for manufactured commodities of $2.29 per pound and a value of $ 0.04 per pound for non-manufactured goods. One more assumption that is necessary to be made is the assignment of the class of cargo (manufactured versus non-manufactured) with the type of truck. These assumptions introduce a bias factor in the evaluation of the inventory cost.

Non-business travel time savings are valued through surveys and behavior models. Under the classes of business and non-business travel it is necessary to investigate the implications for the value of time in personal and business travel.

6.4 Comparing Travel Time Values

Walls and Smith (1998) used the All Items Component of the CPI to update the travel time costs to August 1998 of four different travel time studies (NCHRP 1972, NCHRP 1990, OST 1997, and HERS 1996). Comparing the values of the NCHRP 1972 (1970 dollar) with the values developed by HERS 1996, increases of 377% for the passenger and 526% for trucks travel time cost were observed. Table 10 shows the update to 1996 dollars of the values of travel time from four different sources.

This procedure of updating travel time costs is one of the factors that contribute to the poor fix on the value of travel time. This procedure freezes all the technological improvements implemented in the vehicles and in the transportation infrastructure over the years. Further, it produces a static view of assuming that driver behavior has not changed since the former travel time value was established. Another factor that contributes to the low quality of the value of travel time is the practice of using the results of travel time studies performed outside the United States for applications within the United States. This

practice assumes, for example, that Brazil's roadway network is similar to the United States' network; it also assumes similarity with vehicles and driver behavior between the two countries. In fact, according to the Highway Capacity Manual (HCM 1994), weather, pavement conditions, user's level of familiarity with the facility, and incidents in the traffic flow are the factors considered in the evaluation of the roadways.

Table 10. Composite Listing of Update Travel Time Costs

Source	Units	Autos	Trucks	Combination
USDOT-OST*	$/Person-Hr	$10.80	$16.50	$16.50
MicroBENCOST	$/Veh-Hr	11.37	17.44	24.98
NCHRP	$/Veh-Hr	11.78	19.64	19.64
HERS	$/Veh-Hr	14.30	25.99	31.30

Escalator Factor used: travel time cost- August 1996
*USDOT-OST= US Department of Transportation-Office of Secretary of Transportation.

6.5 Non Business Travel Time

From the perspective of economic theory, non-business trips are those trips that are not on-the-clock trips. The market value assigned for these trips is not by the employer, but by the driver. This assumption creates some difficulties in allocating the appropriate value for each class of drivers. The classical example is the housewife time cost allocation problem. The work performed in the home by the housewife is not compensated by the actual exchange of money, and consequently it is not reported to the Internal Revenue Service, generating the false concept of work performed with no monetary value. However, if a professional provides the same work previously performed by the housewife, this work now has a monetary value. The traditional approach used to solve this problem is to select a percentage of the wage rate and assign this percentage to all non business trips, without considering fringe benefits.

As mentioned before, a value of 55% of the wage rate is recommended for drivers, 40% for passengers with an uncertainty range from 50% to 75%. Using the 1995 census data of 1.59 average vehicle occupancy for all purpose trips the following general formula can be established:

$$TT_{NB} = (\ WP_D \times FWR) + (WP_P \times FWR)\ (OR - 1) \tag{17}$$

Where,

TT_{NB} = travel time for non business
WP_D = wage proportion for drivers (%)
FWR = full wage rate ($)
WP_P = wage proportion for passengers (%)
OR = vehicle occupancy rate

6.6 Business Travel Time

Considering that one of the objectives of this research is to develop user costs for BMS applications that includes no bias in its development process, it is important that the model use concepts that can be supported by a theoretical base accepted by the transportation community. Concepts supported with preponderance of assumptions should be avoided or minimized.

In the case of travel undertaken by employees in the course of work, the economic theory states that the value of travel time consists of the resource value of the time itself, plus the monetary equivalent of whatever utility or disutility results from spending time traveling. Assuming time spent traveling would otherwise be spent working, and that no productive use could be made of travel time, the employee's pre-tax wage rate plus the monetary value of fringe benefits represent the value of time.

Based on these premises the conceptual mathematical model to evaluate business (on- the- clock) travel time, can be expressed in the following way:

$$TT_B = (FWR_D + FB) + (FWR_H + FB)(OCR - 1) + VCC + VIC \tag{18}$$

Where,

TT_B	= travel time for business
FWR_D	= full wage rate for drivers
FWR_H	= full wage rate for helpers
FB	= fringe benefits
OCR	= vehicle occupancy rate
VCC	= vehicle capital costs
VIC	= vehicle inventory costs

The values to be used for wage rate and fringe benefits can be found in the US census for each category of driver. In our case we are interested in truck and car drivers. Trucks and heavy vehicles (military vehicles) are the main source of bridge structure degradation. Extensive research has demonstrated that single unit tandum and triaxle dump trucks have a high potential for overstressing bridge structures. Further, illegal overloading of trucks is now to a level such as to cause significant overstressing of bridge members (Schelling, 1985). The Highway Performance Monitoring System (HPMS) lists thirteen different vehicle categories (Mactavish and Neumann, 1982). HERS uses one classification for cars and four different classifications for trucks: 4-tire truck; 6-tire truck; 3-4 axle truck; 4-axle combination truck; and 5-axle combination truck. The FDOT Weigh-in-motion (WIM) study shows that a 5-axle combination truck represents 50% of the truck traffic composition in the Florida roadway network, and 67% of the truck traffic composition in the Interstate Highway System. Since cars do not affect the bridge structure, and normally they are not required to detour due to bridge limitations, the use of one classification for cars seems appropriate. The classification used by HERS is considered to be equivalent to the truck composition in the Florida Network, and for this reason it will be used to evaluate the basic values of each vehicle. After this evaluation, these values will be adjusted

according to the FDOT weigh-in motion (WIM) truck percentages in the traffic composition (WIM, 1998).

Another factor that must be considered is the appropriate vehicle occupancy rate index to be used in the business travel time evaluation. There are two methods that measure vehicle occupancy: the travel method and the trip method. The travel method computes the vehicle occupancy as person miles of travel per vehicle mile, and the trip method computes the vehicle occupancy as persons per vehicle trip. Because longer trips often have higher occupancies, the travel method generally yields a higher rate. For BMS applications the travel method seems more appropriate. The average vehicle occupancy, measured as person miles per vehicle mile, has decreased consistently over time. This trend is related to an increase in vehicle ownership, and decreases in household size. Data from 1977 indicates a vehicle occupancy rate for all purposes of 1.9; in 1995 this rate decreased to 1.59. The vehicle occupancy rate for trucks is generally accepted to be 1.0 for heavy trucks and 1.1 for small trucks and pick-ups that use helpers on business trips (HERS 1996). Data from Florida Truck Permit Office shows an occupancy rate for trucks of 1.0, and this value will be used for heavy trucks. For small trucks and pick ups the occupancy rate of 1.1 will be used based on HERS data.

6.7 Value of One Hour Travel Time

Table11 presents the value of one-hour travel time by benefit category and vehicle type. Labor, fringe benefits, vehicle capital costs, and vehicle inventory costs are the TTC constituents. The values are in 1997 dollar.

Table 11. Value of One Hour Travel Time for Business and Non-Business Trips by Vehicle Category (1997 dollars)

Category	Vehicle Type					
	Auto	4-Tire Truck	6- Tire Truck	3-4 Axle Comb.	4-Axle Comb.	5-Axle Comb.
Business						
Labor	15.33	14.19	12.9	12.9	12.9	12.9
Fringe Benefits	2.97	5.10	4.6	4.6	4.6	4.6
Vehicle Capital Cost	0.42	0.50	0.86	2.79	1.95	2.00
Vehicle Inventory Cost	0.00	0.00	0.00	0.00	0.50	0.50
Total	18.72	19.79	20.15	22.58	22.24	22.29
Non-Business						
Wage	9.27	N/A	N/A	N/A	N/A	N/A
Vehicle Occupancy	1.59	1.1	1.0	1.0	1.0	1.0

6.7.1 Labor/Fringe Benefits

For autos, the hourly wage per vehicle occupant for on–the-clock trips in 1997 was assumed equal to the Florida median household income of $31,900 (1997 dollar) divided by 2,080 hours/year. The main reason for selecting the Florida median value in place of the US median value for household income was to follow the criteria established previously for prioritizing the use of local data. The fringe benefits value used is the US average of 19.73 % published in the Statistical Abstract of the United States (STA 1989). The US and the Florida Statistical Abstracts use the median to report the household income. Median income is the amount that divides the income distribution into two equal groups, one having incomes above the median and the other having incomes below the median. For households, the median income is based on the distribution of the total number of units including those with no income (FSA, 1998). The median better represents the reality than the mean income that is obtained by dividing the total income of a particular statistical universe by the number of units in that universe.

For trucks, the value used for labor is the one published by the US Census Bureau for weekly median full-time wages for truck drivers, that is \$516/week . For truck helpers the value assigned was the median weekly earnings of full- time wages for freight, stock, and material handlers of \$399/week. The fringe benefit for trucks was the value reported by HERS of 36% which was taken from the Teamster's Union contract for the Central United States.

6.7.2 Vehicle Capital Cost

The evaluation of vehicle capital costs made by the HERS model is made assuming a five-year life with a 15 percent salvage value at the end, and with initial costs taken from the Motor Vehicle Manufacture Association. This approach is appropriate only if all vehicles in the traffic composition work only five years. As mentioned before, the average vehicle age existing in the traffic composition is higher. For this reason a factor will be introduced to lower the value of each vehicle capital cost. This factor is calculated dividing 5-years by the average vehicle age reported in the 1995 summary of travel trends. The values are 0.60, 0.57 and 0.33 respectively for cars, four wheel trucks and heavy trucks.

For heavy trucks, the cost per hour was computed as the average vehicle costs per year divided by the number of hours in service (assumed to be in service only 1600 hour per year). For cars, four and six tire trucks it is assumed that they work 2000 hours per year (HERS, 1999).

6.7.3 Vehicle Inventory Costs

The methodology to calculate vehicle inventory costs, as mentioned before, is based on applying one discount rate to the value of the payload carried by the truck. The HERS model uses a discount rate per hour of 0.0011 percent. This rate is derived from a discount rate of 9.8 percent plus 1 percent. The average payload of a five-axle combination was

assumed to equal 30,000 pounds. The type of cargo carried by all combination trucks was spilt to 35% carrying natural and agricultural products, and 65% carrying manufactured products. The median value per pound of the manufactured products indicated in the Commodity Transportation Survey data is $2.29, and for agricultural and natural products $ 0.04 per pound. With these values, the average payload is valued at roughly $45,000, yielding a time value of $0.505 per hour (HERS, 1999).

6.8 Truck Travel Time Cost for Florida

Using the truck composition data from the WIM study for the FDOT that is in progress at the Civil Engineering Department, University of Florida, only the last three vehicle types listed on Table 12 are statistically relevant for BMS applications. The research result values are showed in Table 12.

Table 12. Research Result Value for TTC

Truck Type	**$/Hr**	**Percent**	**Total (CPK)**
3-4 Axle Truck	22.58	92.0	20.7736
4-Axle Combination	22.24	7.0	1.5568
5-Axle Combination	22.29	1.0	0.2229
Total		100.0	22.5533

CHAPTER 7
AVERAGE VEHICLE OPERATING COSTS FOR BMS

The Vehicle Operating Costs (VOC) developed by this research is 31.3843 cents/Km. This is the marginal cost for a truck run for one extra kilometer per trip. This chapter describes how this value is developed, and the methodology used to evaluate the VOC components (fuel, maintenance, tire and oil change). A VOC for cars and light trucks is presented in Appendix H. The structure of this chapter is shown in Figure 7, where the solid line represents the critical path to develop the new VOC for trucks, and the dashed line represents variable costs not included in this VOC development.

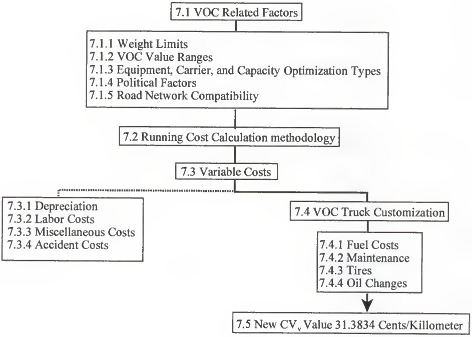


Figure 7. Flow Chart for BMS VOC Development

7.1 VOC Related Factors

According to Equation 19 the motor vehicle operating cost (VOC) is evaluated as a function of average vehicle operating costs per kilometer of detour (CV_V) and detour distance (D_r). CV_v is the cost incurred for a truck to run one kilometer. Since the detour distance is a fixed parameter in the Pontis matrix, the parameter that is variable and sensitive to user costs is the CV_V.

$$VOC= CV_V \text{ x } D_r \qquad (19)$$

Where,

VOC= motor vehicle operating costs
CV_V =average vehicle operating costs per kilometer of detour
D_r =detour distance for the roadway in km

The term motor vehicle for Pontis BMS means a truck. The reason why Pontis focuses only on trucks is due to the fact that bridges are designed with the constraints of bridge formula B, which defines the maximum weight that may be carried on two or more truck axles. This weight is evaluated as a function of the spacing between any two consecutive axles and the number of axles according to the following mathematical relationship:

$$W= 500 \left[(LN/(N-1) + 12N +36\right] \qquad (20)$$

Where,

W =Maximum weight that may be carried on two or more axles, in lbs.,
L =Spacing, in feet, between the outer axles of any two or more consecutive axles
N =Number of axles being considered (Francher and Gillespie, 1997)

7.1.1. Weight Limits

Current federal limits on truck weight, length and width are defined by the Surface Transportation Assistance Act (STAA) of 1992. These limits apply to all vehicles using the Interstate system and other designated federal-aid highways. The weight limits are nominally defined as

9,000 Kg (20,000lb) on a single axle
15,000 Kg (34,000lb) on a tandem axle group
36,000 Kg (80,000lb) maximum gross weight (with a few exceptions) (Fancher and Gillespie, 1997).

Since bridge designers use bridge formula B with the maximum constraint value, that is the maximum vehicle load allowed by legislation, it becomes clear that only heavy trucks cause stress to bridge structures, with high concentrated loads being more stressful. Cars, pickups, and light trucks normally do not cause stress to bridge structures, unless the bridge has severe limitations like historical wood bridges. For this reason, Pontis considers that under normal circumstances, when a bridge is posted, only a percent of trucks must be detoured. However, if the bridge is closed, all traffic must be detoured, and for this reason the evaluation of truck and car operating costs should be considered. The VOC for cars, vans and light trucks are displayed in Appendix H.

7.1.2 VOC Value Ranges

The evaluation of operating cost is a tough challenge faced by the truck industry. According to Cox (1996a), it is impossible to come up with an industry "average" cost per mile, because it depends on a number of variables: the cost of fuel, the number of miles run per year, the truck age, the driver lifestyle, and so on. However an average cost per mile (operations cost) is one of the most useful pieces of information necessary for the business.

Truck operating costs will depend on the type of truck and the type of operation in which they are used. According to Elgin (1998), it is estimated that only ten percent of owner operators know their cost per mile, and that the old proverb of $1.00 per mile just does not apply in today's environment.

Comparing the data from a population of 104,561 tractor trucks associated with 332,838 trailers, distributed into 98 carriers in 1997, the operating costs range goes from 14.25 to 111.04 cents per mile (TFM, 1998). Comparing the operation cost of all Florida truck companies reported in the 1997 Motor Carrier Annual Report a range of 9.3 to 100.9 cents per mile was observed. There are several reasons why there is a large value range in the operating cost reported. The main reason is a lack of a uniform methodology to evaluate operating costs associated with the diversity of equipment and carrier types.

7.1.3 Equipment, Carrier and Capacity Optimization Types

According to the 1999 National Motor Carrier Directory Record Counts, there are 11 equipment types and 19 carrier types hauling commodities. They are listed on Appendix C. To increase complexity, the FHWA uses a classification where vehicles are grouped into 5,000 pound weight categories ranging from 5,000 to 150,000 pounds generating a matrix of 20 vehicle classifications. That is, there is not a uniform truck classification that covers all users.

Other factors that contribute to the difficulty in evaluating truck-operating costs are related to the capacity of each truck. If the truck runs at full capacity, it is classified by the truck industry as truckload-TL . If the truck runs with partial capacity it is classified as Less-Than Truckload – LTD. The ownership type of the truck is also responsible to create new classifications: owner-operators and fleet operators.

7.1.4 Political Factors

Besides the factors listed above that contribute to the difficulty in evaluating truck operating costs, there is also a political issue to be considered. That is the old "political war" between FHWA and the truck industry that is related to the truck maximum load capacity allowed by law, and the appropriate tax share that the truck industry should pay to use the roadway network.

At the same time that the truck industry has a strong lobby to increase the limits on truck weight and length based on the premise that these will improve productivity in the transportation sector, the FHWA feels that the tax share paid by the truck industry is not adequate to cover the related pavement damage. Heavier trucks produce more damage and consequently require more taxation for repair and replacement. As a result of this "political war" an increase of 9.17 percent in the maximum vehicle load has been achieved during the last five decades (Noel et al. 1985), and large discrepancies are observed in the tax share paid by truck owners. In relation to the tax share paid by each FHWA vehicle classification, the 1997 Federal Highway Cost Allocation Study results show a negative equity ratio between revenues and costs. The study presents the estimated cost burden for different vehicle classes and registered weight groups for the Federal related program cost funded from the Highway Trust Fund (HTF) in 2000. Comparing these costs with the Federal user fees paid per mile of travel using the same vehicle class and same year, it was found that the ratio of the shares of revenues contributed by each vehicle class to the share of highway costs are unbalanced. Pick-ups and vans have the largest over payment of any vehicle class. Other vehicle classes in the aggregate that pay more than their fair share are 2-axle single unit trucks, all truck-trailer combinations, and 5- and 6 axle twin trailer combinations. However, 5-axle tractor semitrailers have the largest underpayment of any vehicle class,

followed by automobiles and 3-and 4-axle single unit trucks (USDOT, 1997). Appendix D shows the breakdown of the 2000 Federal highway cost responsibilities and user fee payments by vehicle class and weight group in cents per mile, and the percent cost share. The truck traffic composition in Florida identifies 68% of the trucks as 5 –axle tractor semitralers (WIM, 1998).

Traditionally, truck-operating costs are not disclosed by the truck industry on the premise that it is internal information that is part of the negotiation process. Harrington stated in his 1994 article that the University of Tennessee found a growing desire among shippers for simpler, more predictable carrier pricing structures. Many are tired of the mystery surrounding rates and pricing, and in fact find that mystery a hindrance in serving their customers effectively (Harrington 1994). Some government agencies like the USDA require a disclosure of the truck operating costs in their contracts. Other sources of information are the income statement published by commercial carriers, and data from truck associations. Probably part of this behavior of not displaying clear operating costs is to protect themselves from higher taxation and extra labor costs.

7.1.5 Road Network Compatibility

The majority of the VOC studies made around the world are concerned with discovering the relationship between highway design, pavement condition and road user costs to be used in a transportation investment feasibility analysis. If the findings of these studies are assumed to be applicable to the USA, with some simplifications of the formulas developed, it is possible to generate costs for fuel, oil, tire wear and maintenance costs. However, these studies were developed assuming compatibility between the roadway network from developing countries with the USA roadway network. Since one of the

objectives of this research is to reduce the bias in the user cost calculation these studies will not be valid for our investigation.

7.2 Running Costs Calculation Methodology

Truck running costs are those costs which are incurred solely when a vehicle is operating. They have nothing to do with the costs of owning the vehicle or with the expenses involved in running that transport business as a whole. They are classified as a variable costs and they are comprised of the following four items: fuel, tires, maintenance, and lubricants.

Under the vehicle costs classification there are costs which relate directly and solely to individual vehicles, like licenses, insurance, drive labor, rent, interest and depreciation, that are labeled as “standing costs”(Lowe, 1974).

All those expenses incurred in running a transport business, which cannot be directly attributed to any individual vehicle, are labeled “overhead costs”. All those expenses incurred when the vehicle is running are labeled “running costs”. The combination of standing costs plus overhead costs and running costs are recognized by some sectors of the truck industry as operating costs (Lowe, 1974).

7.3 Variable costs

Running costs are under the classification of vehicle variable costs as listed in Table 13. In reality what Pontis BMS requires is the marginal costs which is the additional cost of running an extra kilometer, e.g. the variable costs.

In some cases, authors use the term “operating costs” with the same meaning as running costs. There is not a consensus in the literature about the classification of variable costs parameters for evaluation of vehicle operating costs.

Table 13. Vehicle Costs Classification Between Fix and Variable Costs

Fixed Costs	Variable Costs
Licenses	Fuel
Insurance	Oil
Depreciation	Tires
Rent	Maintenance
Interest	Tolls
Overhead	Labor

7.3.1 Depreciation

Comparing old studies with recent ones, the main change observed is that depreciation which was considered a variable cost in old studies, is being treated as a fixed cost in recent studies.

Early studies include depreciation as a variable cost. However, it is noticed that it is not included in the comprehensive VOC studies after 1987. Table 14 presents the MicoBENCOST study as a recent study since it was published in 1993. However, the data used to develop its VOC was based on an old study performed by Zaniewsk in Brazil for the years 1975-1982. Today some carriers generate two weights for the same measurement. One hypothetical example can clarify this point. Assume that company A starts a transportation business with 100 new trucks with a policy to depreciate by mile, and to replace the trucks when they reach the 400,000 miles. After a period of time (t) that is defined by the minimum time allowed by the Internal Revenue Service for depreciation and 50% of the trucks really reached of 400,000+ miles and 50% reached only 200,000+ miles in time (t). Technically speaking company A accrued depreciation costs for all 100 trucks as expenses in order to maximize its profit. Further 50% of the fleet would subsequently have zero depreciation in their operating costs.

Table 14. Variable Costs Assigned at Operating Vehicle Cost Studies

VOC study	Misc.	Labor	Fuel	Oil	Tires	Maint.	Depr.	Acc.
Winfrey, 1962			X	X	X	X	X	
Welle, 1966	X	X	X	X	X			
Clafey, 1971			X	X	X	X	X	X
Zaniewski, 1982			X	X	X	X	X	
OOM, 1986	X	X	X		X	X	X	
Chester & Harison, 1987	X	X	X	X	X			
Witconis & Stadden, 1988	X	X	X		X	X		
FHWA, 1991	X		X	X	X	X		
USDA, 1991	X		X		X	X		
MicroBENCOST, 1993			X	X	X	X	X	
MCAR, 1997		X	X	X	X	X		
Berwick, 1997		X	X		X	X		

Hypothetically if a company can extend the life of its trucks by careful maintenance, working for a period of time with a totally depreciated vehicle, the level of profit will increase assuming that the maintenance cost are keep under control. According to Ryder, a large carrier, the operating costs at 500,000 miles were close to those at the million-mile mark (Romba, 1995). In other words, trucks that experience large mileage per year generate lower depreciation per mile, and trucks that experience low mileage per year generate higher depreciation per mile. This policy increases operating costs if the truck is not running, which is contrary to the standard classification of variable costs. For this reason depreciation cannot be considered as part of the running costs. The National Accounting & Finance Council classifies depreciation as a fixed cost (NAFC, 1994).

7.3.2 Labor Costs

The cost for labor was considered in the travel time cost evaluation, and for this reason it will not be included in this section.

7.3.3 Miscellaneous Costs

Expenses under miscellaneous and other costs are those that do not fit in any other accounting category. An investigation of log sheets designed to record cost per mile expenses revealed that miscellaneous and other costs are related more to the driver's life-style than with the equipment (Witconis and Stadden 1988). The cost per mile log sheet published by the Overdrive Book Division & Randall publishing Co. provides a breakdown of the variable costs and divides it into two parts. Variable costs (I) that are related to the truck, and variable cost (II) that are not related to the truck. When a cost per mile log sheet does not break down the variable costs into two parts, they list the costs associated with the truck, and then list miscellaneous costs. From this observation we can conclude that miscellaneous costs are those costs that are not related to the truck running costs.

7.3.4 Accident Costs

Only one study lists accident costs under vehicle operating costs. For Pontis BMS, accident costs will be given a specific treatment. These costs are not treated as part of the VOC costs. They will be discussed in the next chapter.

7.4 VOC Truck Customization

As mentioned before for PONTIS only the truck VOC is important. The values of fuel, maintenance, oil and tires will be calculated. The weigh-in-motion (WIM) for Florida during calendar year 1997 shows that 61.61% of the trucks that use the Florida road network is class 9. Trucks under class 9 are identified as a 3-axle tractor +2-axle trailer, and

3-axle truck +2axle trailer. These vehicles have a Gross Vehicle Weight (GVW) of 80,000+ pounds. Vehicles, class 5 to 8 have a maximum GVW of 68,000 pounds. For the evaluation of the average operating costs, it was assumed that the vehicles under class 5 to 8 would not be required to detour at any bridge site. This is to say that 33.73% of the trucks from the WIM study will not be classified as heavy trucks. Vehicle classes 10 to 13 are combination tractors with a number of axles between five and more than seven with GVW ranging from 80,000 to 140,000 pounds. The percent of heavy trucks considered in this study was calculated to be 92% as a five-axle -80,000 lbs., 7% as a seven axle- 87,000-97,500 lbs., and 1% as nine-axle- 80,000 to 113,500 lbs. (WIM, 1998).

7.4.1 Fuel Costs

Fuel costs are by far the trucker's largest variable expense. Cox indicates that the driver can directly control the fuel consumption in four ways: reduce highway speed, reduce idling, proper tire inflation and smart driving (Cox, 1996b). Engineers from Donaldson Co. add to the Cox list some maintenance items like excessive exhaust back pressure or air intake restrictions that can cause as much as 4% drop in the fuel economy. As a rule of thumb (since it was not possible to trace the source of the named "fuel tests") for each 1-mph increase above 55 mph, 1/10 gallon more fuel per mile is consumed. A truck at 65 mph, on the average, will get 1-mpg less than it does at 55 mph. Idling, particularly fast idling, consumes up to 1 ½ gallon per hour, and according to the Maintenance Council tests, under- inflated tires (70 psi vs. 100psi) can reduce fuel mileage between 1.5% and 3% (HDT, 1990). Campbell points out that fuel purchased under credit plans can cost 6 to 12 cents more per gallon than fuel purchased under cash plans (Campbell 1991). According to MacDonald (1993) if the drivers can run their trucks in the highest possible gear at all times

they will minimize the revolutions per minute, and will maximize mpg at the rate of 1-gallon less fuel per hour (Macdonald 1993).

Kanapton (1981) developed an empirical equation for estimating unit vehicle inter-city freight fuel consumption. It is a linear function of weight in which the constant term represents the fuel consumed in moving the empty vehicle, and the variable term represent the fuel required moving the payload:

$$GPVM = FFC + VFC\ (P) \qquad (21)$$

Where,

GPVM =	is the average line-haul fuel consumption in gallons per vehicle mile.
FFC =	is the fixed component of fuel consumption which is required to overcome resistance of the tare weight and aerodynamic drag.
VFC =	is the variable component of fuel consumption and is the additional fuel required to move the payload.
P =	is the payload

Jack Faucett Associates (1991) updated the Kanapton formula using a 65-mph speed limit, and diesel fuel at $1.25 per gallon. One change was made to Kanapton's formulas: they were modified so that they would be a function of the gross vehicle weight (GVW) instead of a function of payload. Coefficients for fixed and variable costs were obtained for four vehicle types (vans, flatbeds, tanks and dump trailers). The fuel cost per vehicle mile was derived from 1988 dollars. The CPI index was used to update the data to 1998 dollars. These are listed in Table 15 according to the number of axles and GWV.

Table 15. Estimated Cost for Fuel Per Mile by Truck Category

Axle/L	GVW 000 (lbs.)	TL Van (CPM)	Refrigerated Van (CPM)	Flat Bed (CPM)	Tank (CPM)	Hopper (CPM)	Dump (CPM)
5 axle twin	**80**	**23.0**	**27.1**	**22.0**	**21.3**	**15.1**	**15.1**
7 axle twin	80-97	23.7	28.8	23.1	22.8	16.1	16.1
9 axle twin	89,2	23.9	30.9*$_1$	24.2*$_2$	22.8*$_3$	15.1*$_3$	16.1*$_4$

Calculated at GVW of : $*_1$=113,500 lbs. $*_2$=90,000 lbs. $*_3$=80,000 lbs. $*_4$=81,000 lbs.
Source: Adapted from Jack Faucett Associates (1991)

Using these percentages it was possible to evaluate the fuel cost per kilometer. The methodology used was to calculate the average weighted value of each fuel cost listed in table 15 and then split these values into six selected equipment types shown in Table C 1-Appendix C. The results are show in Table 16.

Table 16. Fuel Costs Distribution by Equipment Type

Equipment type	Percent	Fuel Cost Per mile	Totals	
			Cents/ Mile	Cents /Km
TL Van	39.19	23.058	9.03643	
Refrigerated	12.87	22.289	2.86859	
Flat bed	23.19	22.099	5.12475	
Tank	7.26	21.420	1.55509	
Hopper	10.48	15.180	1.59086	
Dump	7.21	15.131	1.06068	
Grand Total 1 (1988 dollar value)			21.23642	
Grand total 2 (1998 dollar value)			28.88506	
Grand Total 3 (1998 cents-per-kilometer)				18.05316

7.4.2 Maintenance

The maintenance cost was calculated based on a formula from Jack Faucett and Associates (1991) where a scaling procedure was used. The formula is weight sensitive and is based on a gross vehicle weight of 58,000 pounds. At this level, a value of 10 cents per vehicle mile is used, and for each 1,000 pounds increase in the GVW .097 cents is added.

The formula for maintenance is:

$$\text{Maintenance Costs} = 10 + [(\text{GVW-58, 000})/1000] * 0.097 \qquad (22)$$

Using the same percent of heavy trucks mentioned in section 7.10, the total of 12.4598 cents per mile was calculated as listed in Table 17.

Table 17. Maintenance Costs for Trucks- CPM/CPK

% truck Composition	GVW (000)	Equation 22 Cents/mile	Total	
			Cents/mile	Cents/Km
92.0	80	12.13	11.1596	
07.0	97	13.78	1.1207	
01.0	113.5	15.38	0.1795	
Grand total 1 (1988 dollar value)			12.4598	
Grand total 2 (1998 dollar value)			16.7001	
Grand total 3 (1998 dollar value)				10.4377

7.4.3 Tires

Tire costs were derived from the Pace Report where truck expenses were reported by 98 carriers in 1997 (TFM, 1998). A value of 3.5557 cents-per-mile was derived using 1987 dollars. Using the CPI index for 1998, the update value is 3.612303, which is equivalent to 2.25765 cents-per-kilometer. The statistics with a 95% confidence level is shown in Table 18.

Table 18. Tire Costs Descriptive Statistics--CPM and CPK

Descriptive Values	Results	
Mean	3.55570(CPM)	2.2576 (CPK)
Standard Deviation	3.37248	
Standard Error Mean	0.34971	
Upper 95 % Mean	4.25026	
Lower 95 % Mean	2.86114	
Number of entries	93	

7.4.4 Oil Change

The majority of vehicle operating cost studies found in the literature includes oil change under fuel. Cox (1997) reports the cost of 1 cent-per-mile after running 125,000

miles in a year. Using the CPI index for 1998, the update value is 1.016119, which is equivalent to 0.6350 cents-per kilometer.

7.5 New CV_V Value

Adding the costs of fuel, maintenance, tire and change oil in cents- per-kilometer, using 1998 dollars, the sum in 31.3834 cents-per-kilometer which is the new CVv value for Pontis. The composition of the total cost is listed in Table 19.

Table 19. New VOC Value for Pontis CV_v Default Value

Variable Costs	Cents per Kilometer
Fuel	18.0531
Maintenance	10.4377
Tire	2.2576
Oil Change	0.635
Total	31.3834

CHAPTER 8
BRIDGE RELATED ACCIDENT COSTS FOR FLORIDA

The new Average Accident Cost (AAC) default value developed by this research is $68,404.39 per accident under the comprehensive approach (including social costs), and $27,365.75 per accident under the economic approach. A total of 10,115 crashes were considered which occurred on 4,505 bridges in Florida in 1996. The injury costs developed by this research range from $3,014,525 to $8,815.72 per injury. They are shown in Table 20. The structure of this chapter is shown in Figure 8.

Table 20. Injury Costs by Injury Type--Year 1996

Injury Type Cost in 1996 Dollars				
Approach	Fatality	Injury A	Injury B	Injury C
Comprehensive	$3,014,525	$211,515.4	$45,927.2	$29,844.7
Economic	$871,697.2	$49,294.19	$12,289.65	$8,815.72

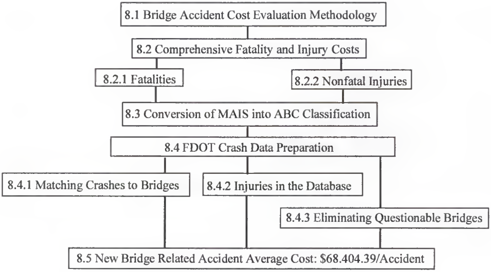


Figure 8. Flow Chart for the Average Accident Costs Development

8.0 Background

According to several studies, bridge related accidents are more severe than other roadway accidents (Chen and Johnston 1987, Turner 1984, Mitchie 1980, Hilton 1973). The literature shows indices that measures the severity of bridge related accidents varying from 2 to 50 times the severity of general roadway traffic accidents. It is difficulty to point to the main cause of a bridge-related accident. One of the former studies on this subject found that the average daily traffic (ADT), sharp curvature at approaches, and bridge width had major effects on bridge related accidents (Raff, 1953). Another study correlates narrow bridge roadway, width and curved approaches as the most important factors contributing to accidents at bridges sites (Hilton, 1973). Empirical observations also have confirmed these results. Recent example was the death of Princess Diana in a car accident that hit a bridge structure (underpass) in France. The main point in establishing that bridge related accidents rates are more severe than roadway accidents is that the higher the accident rate the higher the user cost. According to Chen and Johnston (1987) the average cost of accidents involving bridges was estimated to be 5 to 8 times the costs of general motor vehicle accidents.

8.1 Bridge Accident Cost Evaluation Methodology

The number of bridge related accident occurring in Florida was evaluated using the FDOT bridge accident database for 1996. The data was arranged in a spreadsheet using each line to record an accident. If the accident occurred in a scenario where two or there bridges were involved, an allocation factor was used to split the costs. For two bridges an allocation factor of 0.5 was used, for three bridges the value was 0.33, and for four bridges the value was 0.25.

There are four types of injury classifications in the database selected from the KABCO classification listed in Table E-1, Appendix E. The KABCO injury scheme is designed for police coding at the crash scene. The American National Standards Institute (ANSI) in standard D-16.1 defines it.

Besides the injury classification for each accident, a correspondent property damage is also reported in the FDOT database. A total of 10,015 bridge accidents were found for the year 1996 in the FDOT database involving 4,505 bridges. The average cost of each accident was calculated using Equation 23.

$$ABAC = (FC * K + IAC * A + IBC * B + ICC * C + PDO) * AF \qquad (23)$$

Where,

ABAC =	Average Bridge Accident Cost ($)
FC =	Fatality Cost ($) (Research Resulted Value)
K =	Number of fatalities (FDOT database)
IAC =	Injury Type A cost ($)(Research Resulted Value)
A =	Number of Injury A (FDOT database)
IBC =	Injury Type B cost ($)(Research Resulted Value)
B =	Number of Injury B (FDOT database)
ICC =	Injury type C cost ($) (Research Resulted Value)
C =	Number of Injury C (FDOT database)
POD =	Property damage Only value ($) (FDOT database)
AF =	Appropriation Factor (FDOT database)

8.2 Comprehensive Fatality and Injury Costs

The latest comprehensive study about fatality and injury costs is based on 1994 data prepared by Blincoe (1996), which has its roots in the studies prepared by Miller (1991, 1993a, 1993b, 1994, 1995, 1995b, 1995c). The Blincoe study covers 1994 motor vehicle crashes, where 40,676 people were killed, 5.2 million were injured and 27 million vehicles were damaged. The estimated cost of these motor vehicle crashes was $150.5 billion.

Death, injury and property damage caused by these crashes were the major contributions to the financial loss to victims, their families and to society at large. Included in these costs are: lost productivity; medical costs; legal and court costs;

emergency service costs; insurance administration costs; travel delay; property damage; and work place losses.

The report uses the Abbreviated Injury Scale (AIS) that was developed by the American Medical Association and the American Association for Automotive Medicine (AAAM), which is different from the KABCO classification used by FDOT. Five levels of injuries are used to report the costs under the Maximum Abbreviated Injury Scale (MAIS). For this reason it is necessary to use a methodology to transform the MAIS into the ABC classification. Comparing the components of total costs including fatalities and non-fatalities with only fatalities, and only non-fatalities injuries it was observed that market and household productivity are the components that generate the largest cost contribution for each injury category. Table E-2 in Appendix E shows the percent breakdown of each of the cost components.

Blincoe (1996) refers to a survey made by Greenblat, et al., (1981) which determined the portion of motor vehicle crashes that were reported to the police. They found that for every police-reported crash, there were 27.4 unreported crashes. Blincoe and Faigin (1992) observed a trend in the behavior of drivers involved in accidents. The unreported cases increase with the decrease of injury level. For minor (MAIS 1) injuries, 22 percent were unreported. For property damage only (PDO), 48 percent were unreported.

8.2.1 Fatalities

Fatality estimates for 1994 were obtained from the Fatal Accident Reporting System (FARS). FARS contains information of a complete census of all fatal traffic crashes on public roads in the United States in which a death occurred within 30 days of the crash. The production that is lost by individual crash victims is evaluated using a discount rate of 4 %. There is not scientific proof of the accuracy of this discount rate. However, Blincoe (1996) cites four authors that suggest a discount rate in the range of 2 to 6%.

8.2.2 Nonfatal Injuries

The FARS census provides an accurate count of fatalities. However, there is no equivalent data base for injuries. Estimates of nonfatal injuries were derived from a variety of sources including the Crashworthiness Data System (CDS), the general estimates System (GES), the National Accident Sampling System (NASS), the National Healthy Interview Survey (NHIS), and injury estimates provided to the Federal Highway Administration (FHWA) by individual states (NASS, 1988).

8.3 Conversion of MAIS into ABC Classification

To convert the reported comprehensive costs from MAIS to KABCO, it was necessary to create a conversion table. The methodology was to use the NASS data, which includes the KABCO code, the MAIS score, and a medical description of the injuries. First it was necessary to compute the injury costs by MAIS considering the injury as described in medical documents. To compute A, B, C, equivalent costs, the above values are multiplied by the percentage incidence by MAIS (considering the body region for the A-B-C category) times the cost distribution. The products are then added. In our case the NASS data was used from 1982 to 1986, and is summarized in Table F-1, Appendix F. The percent of each column was calculated generating Table F-2, Appendix F, that is called ABC/NASS distribution factors. The comprehensive and economic costs listed in Table F-3, Appendix F, was then multiplied by the distribution factors generating Table F-2, Appendix F. The resulted values are the comprehensive and economic injury costs. They are listed in Tables F-4 and F-5, Appendix F. The total ABC injury costs from Table F-4 and F-5, Appendix F, are listed on Table 21 and Table 22 respectively for comprehensive and economic values in 1994 dollars. They are update value for 1996 dollars. The reason to update this value is because the FDOT database is in 1996 dollars. They are updated to 1996 dollars using the CPI all items index.

Table 21. Comprehensive Injury Costs, Years 1994 and 1996

Injury Type Cost in 1994 and 1996 Dollars Values				
Year	Fatality	Injury A	Injury B	Injury C
1994	$2,501,292	$199,643.35	$43,350.52	$28,107.2
1996	$3,014,525	$211,515.4	$45,927.2	$29,844.7

Table 22. Economic Injury Costs, Years 1994 and 1996

Injury Type Cost in 1994 and 1996 Dollars Values				
Year	Fatality	Injury A	Injury B	Injury C
1994	$697,736	$46,573.26	$11,675.67	$8,402.04
1996	$871,697.2	$49,294.19	$12,289.65	$8,815.72

The resulted Injury costs expressed in 1996 dollars are used to monetize the number of injuries reported in the FDOT database.

8.4 FDOT Crash Data Preparation

The estimation data set was prepared by merging FDOT's Pontis data with highway crash data maintained by the Florida Department of Highway Safety and Motor Vehicles (HSMV, 1999). The year 1996 was chosen as the analysis year to ensure that all required data would be available for the same year. FDOT maintains Pontis data for 6,383 bridges, almost all state-owned bridges in the state highway system. HSMV maintains crash statistics based on police reports for all roads in the state (Thompson et al., 1998).

8.4.1 Matching Crashes to Bridges

When the Pontis database was established in 1997-98, it relied on inventory data already maintained in the FDOT's Roadway Characteristics Inventory (RCI). The RCI contains the same bridges as Pontis, using the same Bridge IDs, and also using the same

linear reference system (County, Section, Subsection, and Milepost) as the HSMV database. This made it relatively straightforward to develop an automated process to merge the two data sets. Using the RCI data it was possible to precisely locate the beginning and end of each bridge along the roadway. Following the recommendation made by (Brinkman and Mak, 1986), and also by (Johnston et al, 1994), all accidents from the HSMV database that were located within 500 feet of the beginning or end of a bridge were attributed to that bridge. A computer program was written to select all accidents occurring in within 500 ft from each bridge end.

8.4.2 Injuries in the Database

HSMV data are quite extensive for each accident, including not only the location and time of the crash, but also various items of data about drivers, vehicles, weather, injuries, and other circumstances. Very little data are provided about bridges.

Injuries in the crash database are coded according to the traditional A-B-C system (KABCO) expressed in a numeric form, defined as follows:

1 – No injury

2 – Possible injury

3 – Non-incapacitating injury

4 – Incapacitating injury

5 – Fatal injury (within 90 days)

An estimate of vehicle and non-vehicle property damage is also recorded. HSMV follows up on crash reports after 90 days to determine the final count of fatalities and to update the property damage estimate, if available. The initial matching process characterized the injuries in each accident according to the worst injury sustained, and a dollar value of property damage. Later in the study it was found that the most reliable

available accident cost data in the literature was expressed as a cost per injury, rather than a cost per accident. This distinction is important because each bridge-related accident in the Florida data set involves, on average, 2.09 vehicles each vehicle carrying 1.43 persons. The HSMV database does include a listing of each individual (driver, passenger, or pedestrian) and his/her injury level in each accident. Since the matching process included a unique accident identifier for each crash, it was decided later in the study to request the detailed injury list and merge this with the estimation data set to develop a count of injuries by severity level. This made it possible to determine the average user cost per accident. (Thompson et al., 1998).

Out of 11,332 accidents in the matched data set, 6,235 matched more than one bridge. More than 98 percent of these cases involved two or more parallel bridges which shared the same (or nearly the same) linear referencing information. Most of the remaining cases are bridges in series that are less than 1,000 feet apart. Since the functional characteristics of the nearby bridges tend to be identical, it was assumed that each bridge was equally likely to be associated with the accident. The accident counts, injuries, and costs were then divided equally among them. As is evident from the preliminary data analysis, this action has a substantial effect on the statistical properties of the data set by allowing for fractional accident counts, and by reducing the number of bridges having no accidents associated with them. Although the matching process was able to match roadways either on or under each bridge, it was decided to use only data for roadways crossing over bridges. This is consistent with the Pontis assumptions for widening, since widening usually does not affect the characteristics of roadways under bridges. Pontis is able to account for the user benefits of improving the roadway under a bridge when it is replaced, but there

were doubts about the completeness of roadway-under data in the FDOT Pontis database (Thompson et al., 1998).

8.4.3 Eliminating Questionable Bridges.

A large number of bridges in the Pontis database have no corresponding accidents in the crash database. Usually this is because no accidents occurred on that bridge during 1996. However, sometimes this could be because the bridge is outside the coverage of the crash database. For this reason, certain bridges and their associated accidents, if any, were removed from the data set (Thompson et. al., 1998).

Appendix G shows how each bridge related accident is treated in the EXCEL spreadsheet for the case where a crash involves one bridge, two bridges, three bridges and four bridges. An example is also presented for cases where more than one accident occurred in a year for one specific bridge.

8.5 Bridge Related Accident Average Cost

Substituting in Equation 23 the Research Resulted (RR) comprehensive and economic injury costs for year 1996 as listed in Table 20, (that are the factor inputs FC, IAC, IBC, ICC), two predictive accident cost models are created. Equation 24 is the model that uses comprehensive injury costs, and Equation 25 is the model that uses economic injury cost values.

$$ABAC = (3{,}014{,}525.0 * K + 211{,}515.4 * A + 45{,}927.2 * B + 29{,}844.7 * C + PDO) * AF \quad (24)$$

$$ABAC = (871{,}697.2 * K + 49{,}294.19 * A + 12{,}289.65 * B + 8{,}815.72 * C + PDO) * AF \quad (25)$$

Where,

K = Number of Fatalities (FDOT Database)
A = Number of Injury A (FDOT Database)
B = Number of Injury B (FDOT Database)
C = Number of Injury C (FDOT Database)

PDO = Property Damage Only Value (FDOT Database)
AF = Appropriation Factor (FDOT Database)

Using Equations 24 and 25 to calculate the contribution of each factor for the bridge population considered, and dividing that total number of 10,015 accidents occurring in Florida in 1996, a unit cost per accident is then generated. The final result is listed in Table 23.

Table 23. Bridge Related Accident Unit Costs, for Florida

Method	Total Costs($)	Number of Accidents	Unit Cost 1996 dollar	Unit Cost 1998 dollar
Comprehensive	655,837,765	10015.40	65,482.91	68,404.39
Economic	262,373,413	10015.40	26,196.99	27,365.75

The Comprehensive value of $68,404,39 includes all social costs, and it is the new average accident cost default parameter to be used in Pontis BMS for Florida applications. It will be used as a selected user average cost per accident in the sensitivity analysis study in the next chapter.

CHAPTER 9
PONTIS USER COST SENSITIVITY ANALYSIS

A sensitivity analysis is made to test the hypothesis of this dissertation. The default values of this research were fed into Pontis BMS software and ran under 19 different scenarios. The original Pontis default values were also fed into Pontis BMS software and ran under 20 different scenarios. Comparing the results, the sensitivity of the average accident cost increased 49.12 %, the sensitivity of the travel time decreased 5.67 %, and the sensitivity of the vehicle operating costs decreased 2.8%, generating an overall increase of 25.95% in the project attractiveness index. Each Pontis default value is increased by 49.12%, 24.0% and 16 % respectively for accident costs, travel time and vehicle operating cost. The use of the research resulted default values prioritize more projects that are related with accidents, and consequently increase the safety of the bridge network. The structure of this chapter is shown in Figure 9.

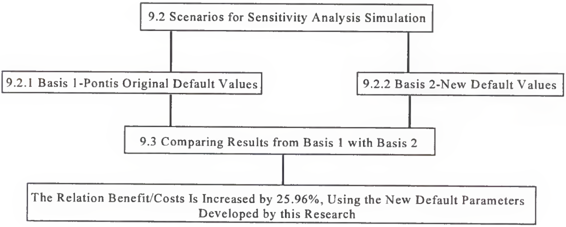


Figure 9. Flow Chart for User Cost Sensitivity Analysis

9.0 Background

The Pontis BMS has a module named "Programming" that is used to develop network strategies and define multi-year, budget constrained programs for preservation and functional improvement projects. For this case, we will select the functional improvement projects to run different scenarios to conduct a "what-if" analysis. Improvements are aimed at making the structure better able to serve the functional demands placed upon it. Standard types of functional improvement actions included in Pontis are widening, raising, strengthening, scour protection, and seismic retrofit (Pontis, 1997).

The database selected to run the different scenarios was the Pontis 34-default database named Pontis 34SQLAny Sample DB, which has the data of 524 bridges. The budget restrictions used were the Pontis default value of $1,100,000/yr over a five year period, 1998 to 2002. A replacement criterion was 100%, and the minimum project cost was set at $0.00 (Pontis, 1998a).

"What-if" analyses were conducted changing the user cost parameters of the cost matrix. As mentioned before there are three different user costs listed in the cost matrix: detour per hour; detour per kilometer; and average per accident. Weight parameters used were set at one. That is, the user cost weight is 100, this means that user costs are treated on par with agency costs. Since the aim of the sensitivity analysis study is to find the benefit if we change user cost parameters, no change was made in any agency cost parameters. The default values and the research result values (RR) are listed in Table 24.

Table 24. User Cost Default from Pontis and Research Result Values

Parameters	Detour per Hour ($/hr)	Detour Per Km ($/Km)	Average Per Accident ($)
Pontis Default values*	19.34	.25	37,600.00
Research Result values	22.55	.3138	68,404.39

* (Pontis, 1997a)

The default values from Pontis will be considered as " basis 1", and the research result value will be considered as "basis 2". Increments were made in both directions (negative and positive) for each user cost parameter for each category. The ranges of those increments were between -20 to +20 percent for the detour per hour parameters, -16 to +52 percent for the detour per kilometer parameters, and –15 to +38 percent for the average per accident parameters.

9.1 Parameters Definitions

The result of each program simulation is reported in several report types. The report PROG003- "Total needs vs. programmed work over time" was selected. This report compares cost and benefits of feasible needs vs. programmed work that could be conducted within the budget constraints in each year of the current scenario. It provides a comparison for each combination of district functional class, ownership and NHS status. The report also identifies the total work programmed for the number of structures in the inventory. A report is produced containing the actual needs by dollar value and year. Interpretations of items in this report are listed below.

- Budget--The total budget for each year, in this case, is $1,100,000/year (Pontis, 1997a).
- Feasible needs-cost--the cost of following the optimal preservation and functional improvement policies with no budget constraints (Pontis, 1997a).

- Feasible needs benefit--the annual long-term benefit that would accrue by following the optimal policy. These benefits are the savings that would result from taking the recommendation actions as opposed to doing nothing (Pontis, 1997a).
- Work programmed cost--the work cost are calculated by the programming simulation, which selects projects with the highest incremental benefit cost ratios up to the specific budget constraints for each program year (Pontis, 1997a).
- Work programmed benefit--the annual long-term benefits that would accrue by completing the programmed work. These benefits are the savings that would result from taking these actions rather than doing nothing. Comparing this to the benefits due to the needs will give an idea of how current budget constraints may be necessitating higher expenditures for preservation over the long term (Pontis, 1997a).

9.2 Scenarios for Simulation

Two sets of data are used to feed the software module "programming." The first set of data are the user cost default values used in the latest version of PONTIS software (version 3.4), and the second set of data are the user cost values developed by this research. Both sets of data are listed in Table 23. Each set of data will provide data that will be used as a basis to compare the results of each data input simulation.

Using the first set of data, the total benefits calculated are $2,506,904.00, which is named, "basis 1". Using the second set of data, the total benefits calculated showed an improvement of 22.09% resulting in $3,060,723.00, which is named "basis 2". Each simulation will generate a correspondent value for total benefits that will be compared with the benefits calculated for each basis.

The percent change of the total benefits due to variations in the user cost parameters will be calculated using Equation 26.

$$\% \text{ Change} = (B_{ci} - B_{bj}) / B_{bj} * 100 \qquad (26)$$

Where,

B_{ci} is the total benefits calculated due to changes in the user cost parameter i.
B_{bj} is the total benefits of the base j in consideration
i type of user cost
j base 1 or base 2

9.2.1 Basis 1 Scenarios - Pontis Default Values

For "basis 1", twenty different scenarios were run. The user cost parameters used, the total benefits generated and the percent change occurring in each simulation are listed in Table 25.

9.2.1.1 Basis 1 Sensitivity Analysis

The detour per hour user cost parameter changed six times in the range of +20% to –20% from the original default value. These changes in the used cost parameter generated variations in the benefit cost in the range of +7.17 % to –7.17%.

The detour per kilometer user cost parameter changed six times in the range of +52% to –16% from the original default value. These changes in the used cost parameter generated variations in the benefit cost in the range of 16.34% to –5.02%.

The average accident user cost parameter changed five times in the range of +38 to –15% from the original default value. These changes in the used cost parameter generated variations in the benefit cost in the range of +3.95% to –2.08%.

The main reason not to use a uniform variation between all user cost parameters is due to the fact that some simulations used user cost data found in the literature.

Table 25. Benefit Percent Change Due to User Costs Percent Change Under Different Scenarios (Using Pontis Default Values)

Total Benefits $(000)	User cost % change (%)	Benefits % change (%)	Detour per Hour ($/hr)	Detour per Km ($/Km)	Average per accident ($)
Basis 1					
2,506	0	0	19.34	0.25	37,600
Changes in detour per hour user cost parameter					
2,598	10	3.57	21.27	0.25	37,600
2,641	15	5.37	22.24	0.25	37,600
2,686	20	7.17	23.21	0.25	37,600
2,417	-10	-3.57	17.41	0.25	37,600
2,372	-15	-5.37	16.44	0.25	37,600
2,327	-20	-7.17	15.47	0.25	37,600
Changes in detour per kilometer user cost parameter					
2,601	12	3.77	19.34	0.28	37,600
2,632	16	5.02	19.34	0.29	37,600
2,759	32	10.05	19.34	0.33	37,600
2,916	52	16.34	19.34	0.38	37,600
2,443	-8	-2.51	19.34	0.23	37,600
2,380	-16	-5.02	19.34	0.21	37,600
Changes in average per accident user cost parameter					
2,576	20	2.75	19.34	0.25	45,120
2,541	10	1.37	19.34	0.25	41,360
2,559	15	2.08	19.34	0.25	43,300
2,605	38	3.95	19.34	0.25	51,960
2,472	-10	-1.37	19.34	0.25	33,840
2,455	-15	-2.08	19.34	0.25	31,960
2,437	-20	-2.75	19.34	0.25	30,080

Changes made in all user costs parameters analyzed for "basis 1" generated linear changes in the work-programmed benefit. The linear function is valid for positive or negative changes in each user cost parameter. That is, savings will increase or decrease in the same proportion as the positive or negative increment observed.

The results show that the most sensitive user cost parameter is the detour per hour, followed by the detour per kilometer and the average accident cost parameter. One percent increase/decrease in each of these user cost parameters generates small percents in increase/

decrease on the benefit side. Table 26 shows the resulting benefit increase percent and the correspondent value in dollars due to one percent increase in the user cost value.

Table 26. User Cost sensitivity Ranking Against % changes in Benefit-- "Basis 1" --(Using Pontis Default Values)

User Cost Sensitivity Order	User Cost % change	Benefit % change	Change in total Benefits ($)
1st Detour/km	+1%	+0.3585 %	8,774
2nd Detour/hr	+1%	+0.3138 %	7,771
3rd Average Accident.	+1%	+0.1379 %	3,259

9.2.2 Basis 2 Scenario Research Result Default Values

For "basis 2", eighteen different scenarios were run. The user cost parameters used, the total benefits generated and the percent change occurred in each simulation are listed in Table 26.

9.2.2.1 Basis 2 Sensitivity Analysis

The detour per hour user cost parameter changed six times in the range of +20% to –20% from the original default value. These changes in the used cost parameter generated variations in the benefit cost in the range of +6.76 % to –6.767%.

The detour per kilometer user cost parameter changed six times in the range of +19.35% to –19.35 % from the original default value. These changes in the used cost parameter generated variations in the benefit cost in the range of 6.10% to –6.10%.

The average accident user cost parameter changed five times in the range of +20% to –20% from the original default value. These changes in the used cost parameter generated variations in the benefit cost in the range of +4.11% to –4.11%.

Changes made in all user costs parameters analyzed for "basis 2" generated linear changes in the work-programmed benefit. The linear function is valid for positive or

negative changes in each user cost parameter. That is, savings will increase or decrease in the same proportion as the positive or negative increment observed.

The "basis 2" results shows the same behavior as the results observed for the "basis 1" sensitivity analysis, that is, the most sensitive user cost parameter is the detour per hour, followed by the detour per kilometer and the average accident cost parameter. One percent increase/decrease on each of these user cost parameters generates small percent increase/ decrease in the benefit side. Table 27 shows the resulted benefit increase percent and the correspondent value in dollars due to a one percent increase in the user cost value.

Table 27. User Cost Sensitivity Ranking Against % Changes in Benefits--Basis 2--(Using Research Resulted Default Values)

User Cost Sensitivity order	User Cost % change	Benefit % change	Change in total Benefits ($)
1st Detour/hr	1%	0.338334	10,476.85
2nd Detour/km	1%	0.305296	9,769.828
3rd Average Accident.	1%	0.205569	5,999.017

The same pattern observed for "basis 1" was observed for the "basis 2" scenario. Changes made in all user costs parameters analyzed "basis 2" generate linear changes in the work-programmed benefit.

The result confirmed that the most sensitive user cost parameter is the detour per hour, followed by the detour per kilometer and the average accident cost parameter. However, the benefit percent change for the one percent increase/decrease in each of these user costs was different from the results found in "basis 1". The linearity observed in "basis 1" for all three parameters was also observed in "basis 2" for all three parameters. Table 28 shows the resulted benefit increase percent and the correspondent value in dollars due to a one- percent increase in the user cost value.

Table 28. Benefit Percent Change Due to User Costs Percent Change Under Different Scenarios--Basis 2--(Using Research Resulted Default Values)

Total Benefits $	User cost % change (%)	Benefits % Change	Detour per Hour ($/hr)	Detour per Km ($/Km)	Average per accident ($)
Basis 2					
3,097,205	0	0	22.55	0.31	68,404
Changes in detour per hour user cost parameter					
3,306,783	20	6.766682	27.06	0.31	68,404
3,202,226	10.02217	3.390831	24.81	0.31	68,404
3,149,716	5.011086	1.695432	23.68	0.31	68,404
2,887,628	-20	-6.76665	18.04	0.31	68,404
2,992,649	-9.97783	-3.37582	20.3	0.31	68,404
3,044,694	-5.01109	-1.69543	21.42	0.31	68,404
Changes in detour per kilometer user cost parameter					
3,286,318	19.35483	6.1059245	22.55	0.37	68,404
3,191,762	9.677419	3.0529784	22.55	0.34	68,404
3,160,242	6.451612	2.0352867	22.55	0.33	68,404
2,908,092	-19.35483	-6.105925	22.55	0.25	68,404
3,002,649	-9.677419	-3.052946	22.55	0.28	68,404
3,034,168	-6.451612	-2.035287	22.55	0.29	68,404
Changes in average per accident user cost parameter					
3,224,543	20.00029	4.111384	22.55	0.31	82,085
3,160,869	9.999415	2.055530	22.55	0.31	75,244
3,129,038	4.999707	1.027797	22.55	0.31	71,824
2,969,871	-20.00029	-4.111255	22.55	0.31	54,723
3,033,535	-10.00087	-2.055724	22.55	0.31	61,563
3,065,377	-4.999707	-1.027636	22.55	0.31	64,984

9.3 Comparing Results From "Basis 1" and "Basis 2"

Changes in the total benefits of the comparative basis generate changes in the sensitivity of each user cost parameter. Detour per hour and detour per kilometer showed more sensitivity under a lower value base, and accident costs showed more sensitivity under a higher value base. These changes are due to the new proportion of each part in the composition of the total benefits that is given by the summation of detour per hour benefits plus detour per kilometer benefits plus average accident benefits. The major change observed is in the average accident user cost parameter. It increased + 49.12 %. This is due

to the increase of 81.93% in the basis value. As a result of this increase the detour per hour and detour per kilometer parameters decreased from "basis 1" to "basis 2" in the proportions of -5.67% and –2.87% respectively.

Table 29 shows the variability of each user cost parameters in accordance with the calculated basis.

Table 29. User Costs Variability Under two Different Calculation Basis

User Cost Parameter	User Cost (Δ%) Δ%=% difference	Benefits basis 1 (Δ%) Δ%=% difference	Benefits basis2 (Δ%) Δ % =% difference
Detour per hr	+1	0.3586855	+0.338334
Detour per Km	+1	0.314322	+0.305296
Aver. accident	+1	0.1378513	+0.205569

The results of the sensitivity study agree with the application example in Chapter 5. However, a generalization stating that the hierarchy of the user cost sensitivity will be the same for each case cannot be confirmed. For this sample of bridges, we observed this hierarchy; however, for another sample it maybe different.

Comparing the same increment observed for each user cost parameter, it is observed that the contribution of detour costs (hour + kilometer) is 83.54%, and the contribution of average accident costs is only 16.46% on the benefit side.

Since the main objective to is to shorten the travel time between points A and Bin the network, it is expected that if road users cannot use the bridge, the travel time will be longer and consequently the associate user costs will increase. The sensitivity analysis among the three user costs parameters seems to confirm this behavior by showing the detour costs being more sensitive then others.

The results of this sensitivity study shows that using the new default values developed by this research, the user cost benefits are increased by 23.59%, and the relation, benefit/cost, is increased by 25.96%. These new values change the priority of projects by giving a higher priority to projects that are related with safety in place of those that are related with user expenses. Since each new default parameter resulted in higher benefit cost ratios, than those produced by the original default parameters, the hypothesis stated for this research is true

CHAPTER 10
CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

1. The hypothesis of this dissertation proved to be correct. That is, the default values in the Pontis BMS mathematical model used to evaluate user cost benefits, are not suitable to evaluate user cost benefits for Florida's bridge network.

2. The BMS user cost customization proved to be necessary to increase the efficiency and quality of the data generated for decision makers.

3. The major contribution of the findings of this research was the disclosure that all three default values previously used in Pontis did not properly represent the reality of Florida user costs. Also, the use of these values provide false information for the decision makers, causing them to underestimate the validity of the use of a user cost methodology as a valuable decision tool. The use of under-estimated user cost values does not emphasize the necessity to take immediate actions for bridge related problems, creating an illusion that it is safe to postpone actions.

4. User cost parameters for Florida BMS applications developed by this research resulted in the following revised default values:

Detour per Hour	$ 22.55
Detour per Kilometer	$ 0.3138
Average Accident Costs	$ 68,404.39

Compared to previous values of:

Detour per Hour	$ 19.34
Detour per Kilometer	$ 0.25
Average Accident Costs	$ 37,600.00

5. The development of a customized value for all three user cost default parameters demonstrated that it is necessary to increase the Pontis average accident default value by 45.03%, an increase in the Pontis detour per kilometer default value by 24%, and increase the Pontis detour per hour default value by 16.60%.
6. The project attractiveness index measured by the benefit/cost ratio increased 25.96% with the use of the customized user cost parameters developed by this research.
7. The willingness-to-pay approach used to evaluate accident costs was best suited to replicate the reality of Florida bridge related accidents.
8. The detour per kilometer user cost parameter resulted in the most sensitive parameter in the Pontis mathematical model. The increase of one cent in the truck running costs resulted in an increase of $31,519.00 in total benefits.
9. The detour per hour user cost parameter resulted in the second most sensitive parameter in the Pontis mathematical model. The increase of one dollar in the truck driver travel time resulted in an increase of $ 24,512.00 in total benefits.
10. The detour per hour user cost parameter resulted in the third most sensitive parameter in the Pontis mathematical model. The increase of $1,000.00 in the average accident cost resulted in an increase of $ 9,307.00 in total benefits.

10.2 Recommendations

1. It is recommended that the new values be used as default values in the Pontis software for Florida applications as follows:

Detour per Hour	$ 22.55
Detour per Kilometer	$ 0.3138
• Average Accident Costs	$ 68,404.39

2. For cases where all traffic is diverted, and detour for vehicles other than trucks is necessary, the following user cost parameters are recommended:

Table 30. Car, Vans and Small Trucks VOC Values

Vehicle Size	Total Cents/ Kilometer
Subcompact	7.2
Compact	7.73
Intermediate	8.70
Full Size Car	9.30
Compact Pickup	8.1
Full size Pickup	10.58
Minivan	9.15
Full Size Van	12.61

3. For cases where all traffic is diverted, the following user costs parameters are recommended:

Table 31. Travel Time Costs for Auto, and Five Truck Types

	Vehicle Type					
Category	Auto	4-Tire Truck	6-Tire Truck	3-4 Axle Truck	4-Axle Comb.	5-Axle Comb.
Business	18.72	19.79	20.15	22.58	22.24	22.29
Nonbusiness	9.27	N/A	N/A	N/A	N/A	n/A

4. It is recommended that the cost matrix for Pontis be improved to accept data up to three decimal points for more accurate results. Currently if the third decimal is over five it rounds to the next highest second decimal. If the third decimal is bellow five, it rounds to zero.

APPENDIX A
PONTIS OUTPUT REPORTS

Inspection Reports
1-Inspection structure, Inspection , Appraisal sheet
2-Inspection Tab Card Report
3-Inspection Schedule
4-Inspection Resources
5-NBI Time series
6- Element time series
Preservation Results Reports
1- Total needs vs. programmed work over time
2-Element category needs vs. programmed work over time
3-Element material needs vs. programmed work over time
4- Element type needs vs. programmed work over time
5 -Annual results by element
6-Total preservation needs vs. programmed work over time
7-Total element category programmed work over time
8- Total element material programmed work over time
9- Total element category needs over time
10- Total element material needs over time
11- Element category and material condition over time
12- element condition over time
13-Preservation model details
Network- level Program Results Report
1-Annual needs vs. Programmed over time
2- District allocation of needs vs. programmed work over time
3-Funtional class allocation of needs vs. programmed work over time
4-Ownership and district allocation of needs vs. programmed work over time
5- Ownership and NHS allocation of needs vs. programmed work over time
6- Annual allocation of needs and work by district
7- Annual allocation of programmed work by district
8- Annual allocation of programmed work by functional class
9- Annual allocation of programmed work by ownership and district
10- Annual allocation of programmed work by ownership and NHS status
11-Action category cost and benefit over time
12-Action Type costs and benefit over time
13-Total action cost by category over time

14-Annual cost and benefit by action type
Project-Level Program Results Reports
1-Project priority list
2-Project cost and benefits
3-Project schedule
4-Projects under implementation
5-Project-level cost
6-Project identification and status
7-Model-related project data
8-Functional improvements for all types of project status
9- Preservation actions for all types of project status
Historical Project Reports
1- Historical project listing
2-Historical functional improvement listing
3- Historical preservation listing
4-Historical project data sheet

Reference: Pontis Release 3.2 User's Manual vol.1- ASSHTO

APPENDIX B
FDOT PONTIS DEFAULT VALUES POLICY

Variables in Pontis related to widening benefits that are related to user costs, and where defined by FDOT policies are listed on Table B1.

Table B-1. Widening Variables Related with User Costs Adopted by the FDOT

Model Parameters Variable	Model	Florida Default
High approaching alignment rating	widening	9
Low approaching alignment rating	widening	2
Regression Constant (AccRiskCoeff)	widening	200
Regression Constant (GaccRiskC	widening	6.5
Short bridge threshold	widening	60
Approach width factor	widening	0.9
Design lane width	widening	3.7
Design shoulder width -Interstates	widening	4.9
Design shoulder width- other classes	widening	2.4

Source : (Thompson et al. 1998)

Variables in Pontis related to raising benefits that are related with user costs, and where defined by FDOT policies are listed on Table B2.

Table B-2. Raising Variables Related with User Costs Adopted by FDOT

Model Parameters Variable	Model	Florida Default
Height detour defaut	Raising	0
Height detour point A (X)	Raising	0
Height detour point A (y)	Raising	0
Height detour point B (X)	Raising	3.96
Height detour point B (Y)	Raising	10.81
Height detour point C (X)	Raising	4.11
Height detour point C (Y)	Raising	0.18

Table B-2--continued.

Model Parameters Variable	Model	Florida Default
Height detour point D (X)	Raising	4.27
Height detour point D (Y)	Raising	0.05
Height detour point E (X)	Raising	4.42
Height detour point A (Y)	Raising	0.027

Source : (Thompson et al. 1998)

Variables in Pontis related to replacement benefits that are related with user costs, and where defined by FDOT policies are listed on Table B3.

Table B-3. Replacement Variables Related with User Costs Adopted by FDOT

Model Parameters Variable	Model	Florida Default
Height eligibility point A	Replacement	2.3
Height eligibility point B (X)	Replacement	18
Height eligibility point B (Y)	Replacement	64.32
Height eligibility point C (X)	Replacement	41
Height eligibility point C (Y)	Replacement	83.57

Source : (Thompson et al. 1998)

Variables in Pontis related to strengthening benefits that are related to user costs, and where defined by FDOT policies are listed on Table B4.

Table B-4. Strengthening Variables Related with User Costs Adopted by FDOT

Model Parameters Variable	Model	Florida Default
Weight detour point A	Strengthening	2.3
Weight detour point B (X)	Strengthening	18
Weight detour point B (Y)	Strengthening	50.425
Weight detour point C	Strengthening	41

Source : (Thompson et al. 1998)

Variables in Pontis related to detour benefits that are related to user costs, and where defined by FDOT policies are listed on Table B5.

Table B-5. Detours Variables Related with User Costs Adopted by FDOT

Model Parameters Variable	Model	Florida Default
Default road speed, FC 1	Detours	94
Default road speed, FC 11	Detours	91
Default road speed, FC 12	Detours	83
Default road speed, FC 14	Detours	83
Default road speed, FC 16	Detours	48
Default road speed, FC 17	Detours	48
Default road speed, FC 19	Detours	32
Default road speed, FC 2	Detours	87.8
Default road speed, FC 6	Detours	80
Default road speed, FC 7	Detours	80
Default road speed, FC 8	Detours	40
Default road speed, FC 9	Detours	40
Default truck percent	Detours	5
Detour speed factor	Detours	.80

Source : (Thompson et al. 1998)

Table B6- FDOT Bridge Data Adopted for Pontis

FDOT Bridge Data Variable	Model	Median	Max.	Min.
Functional class (bridge)	Bridge table	11	19	1
Detour distance	Roadway Table	1	999	0
Detour speed	Roadway Table	N/A	N/A	N/A
Functional class (roadway)	Roadway Table	11	19	1
Roadway speed	Roadway Table	N/A	N/A	N/A
Truck fraction	Roadway Table	8	80	0
Vertical clearance	Bridge table	99.99	100	0
Operating rating	Roadway Table	58.9	100	2.7
Future volume	Roadway Table	25000	538375	0
Future volume year	Roadway Table	2018	2029	2000
Traffic volume	Roadway Table	13000	648500	0
Traffic volume year	Roadway Table	1995	2031	1980
Bridge Length	Bridge table	51.8	10887.5	1.8
Approach Alignment rate	Inspection Event table	8	9	1
Approach road width	Roadway Table	12.1	85.3	1.2
Number of lanes	Roadway Table	2	84	1
Roadway width	Roadway Table	12	66	1

Source: (Thompson et al. 1998)

APPENDIX C
EQUIPMENT AND COMMODITY CARRIER TYPES

Table C-1 and C-2 are adapted from the 1999 National Motor Carrier Directory Record Counts. The total by equipment type in Table C-1 is 34,128. The total by carrier type listed on table C-2 is 24,571.

Table C-1. Percent by Equipment Type

Type		Percent
5.	Van	39.19
6.	Flatbed	23.19
7.	Refrigerated	12.87
8.	Open Top	10.48
9.	Tank	7.26
10.	Others	3.53
11.	Chassis	1.32
12.	Autorack	1.25
13.	Livestock	0.45
14.	Logging	0.42
15.	Horse Vans	0.04
	Total	100.00

Table C-2. Distribution According Carrier Type by Commodity

	Commodity	Percent
1.	General Freight	46.8
2.	Agricultural Commodities	10.1
3.	Heavy Hauling	8.8
4.	Bulk Commodities	7.3
5.	Household Goods	7.2
6.	Building Materials	6.2
7.	Refrigerated Solids	3.4
8.	Petroleum Products	2.4
9.	Tank Truck	1.9
10.	Motor Vehicle	1.4
11.	Mobile Home	0.8
12.	Refrigerated Liquids	0.8
13.	Package	0.8

Table C-2--continued

	Commodity	Percent
14.	Hazardous Products	0.7
15.	Others	0.6
16.	Forest Products	0.4
17.	Cement Hauler	0.2
18.	Armored	0.1
19.	Horse Carrier	0.1
Total		100.0

APPENDIX D
YEAR 2000 FEDERAL HIGHWAY COST AND FEE RESPONSIBILITIES

Table D-1 shows the breakdown of the 2000 Federal highway cost responsibilities, user fee payments by vehicle class and weight in cents per mile, and the percent cost share.

Table D-1 Cost Responsibilities and User Costs Fee Payments by Vehicle Class and Weight and the Percent Cost Share- Cents per Mile.

Vehicle Class/ Registered Weight	Cost Responsibility	Fee Payment	Equity Ratio Revenue/Cost	Cost Share (%)
Autos	0.65	0.64	0.98	43.8
Pickups and Vans	0.65	0.89	1.37	15.5
Buses	2.57	0.27	0.11	0.7
All Passenger Vehicles	0.66	0.70	1.06	59.9
Single Unit Trucks ≤ 25,000 lb.	1.75	2.66	1.52	3.6
25,001-50,000 lbs.	4.38	3.18	0.73	3.1
> 50,000 lb.	14.6	6.57	0.45	4.0
All Single Units	3.51	3.13	0.89	10.7
Combination Trucks ≤ 50,000 lb.	2.78	4.53	1.63	0.7
50,001 – 70,000 lb.	4.25	6.24	1.47	1.7
70,001 - 75,000 lb.	6.25	6.24	0.99	1.4
75,001 - 80,000 lb.	7.08	6.41	0.91	22.5
80,001 -100,000 lb.	12.50	7.18	0.57	1.8
>100,000 lb.	16.60	8.30	0.50	1.4
All Combinations	6.90	6.20	0.90	29.4
All Trucks	5.48	4.92	0.90	40.1

Source: 1997 Federal Highway Cost Allocation Study- USDOT 1997

APPENDIX E
KABCO INJURY CLASSIFICATION DEFINITION

Table E-1 KABCO Injury Classification System[1] used in Florida

K or F (Killed /Fatal Injury)- Any injury that results in death within 30 days of occurrence.

1. (Incapacitating Injury)--Any injury, other than a fatal injury, which prevents the injured person from walking,, driving, or normally continuing the activities the person was capable of performing before the injury occurred. –Inclusions: Severe lacerations, broken or distorted limbs, skull or chest injuries, abdominal injuries, unconscious at or when taken from the accident scene; unable to leave accident scene without assistance; and others. -Exclusions: Momentary unconsciousness, and others.

2. (Nonincapacitating / Evident injury)--Any injury, other than a fatal injury or an incapacitating injury, which is evident to observers at the scene of the accident in which the injury occurred.- Inclusions: Lump on head, abrasions, bruises, minor lacerations, and others. –Exclusions: Limping (the injury cannot be seen), and others.

3. (Possible injury)- Any injury reported or claimed which is not a fatal injury, incapacitating injury or nonincapacitating evident injury.- Inclusions: Momentary unconsciousness, claim of injuries not evident, limping, complaint of pain, nausea, hysteria, and others.

15. (property damage)-Harm to property that reduces the monetary value, and others. -Inclusions: Harm to wild animals or birds that have monetary value,

and others.
-Exclusions: Harm to wild animals or birds that lack monetary value; harm to a snow bank unless, for example additional snow removal costs are incurred because of the snow; mechanical failure during normal operation, such as tire blowout, broken fan belt, or broken axle; and others.

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[1]Adapted from National Safety Council and Miller (1991)

Table E-2. Components Composition of 1994 Motor Vehicle Crashes

Components	Total Costs		
	Fatalities + Non-fatalities (%)	Fatalities (%)	Non-Fatalities (%)
Medical costs	11.3	1.5	22.5
Market Productivity	28.2	69.3	25.8
Household Productivity	8.2	15.9	8.0
Insurance Administration	6.9	3.4	9.0
Workplace Cost	2.6	0	3.3
Legal Costs	3.9	7.3	4.6
Property damage	34.6	1.1	23.9
Others	4.3	1.5	2.9
Total	100	100	100

APPENDIX F
CONVERSION OF MAIS INTO ABC INJURY COST TABLES

NASS Injuries

The National Automotive Sampling System (NASS), formerly the National Accident Sampling System, is the mechanism through with the National Traffic Safety Administration (NHTSA) collects nationally representative data on motor vehicle traffic crashes to aid in the development, implementation, and evaluation of motor vehicle and highway safety countermeasures. It collects data on an annual sample of approximately 55,000 police-reported traffic crashes and additional detailed information on an annual sample of 5,000 police-reported crashes involving passenger vehicles towed from the crash scene due to damage resulting from the crash. The vehicles under consideration are cars, pickup trucks, vans, and sport vehicles. Motorcycle, bicycles, horse-drawn carriages, trucks are not considered in this database, USDOT-NTSA (1998).

A sample of 12,345,468 accidents occurring between 1982-1986 from the NASS database is reported in Table F-1. This data is used to generate the distribution factors used to convert MAIS injury classification into ABC injury classification (KABCO).

Table F-1 1982-1986 NASS Injuries

MAIS	Injury A	Injury B	Injury C	TOTAL
1	1106880	4039582	4731293	9877755
2	628338	636692	445949	1710979
3	376136	153411	99524	629071
4	65427	13620	4229	83276
5	39650	3518	1219	44387
TOTAL	2216431	4846823	5282214	12345468

Source: National Automotive Sampling System

Table F-2 is generated by dividing the total of each injury type reported in Table F-1 by the respective MAIS number of injuries.

Table F-2 ABC/NASS Distribution Factors

MAIS	Injury A	Injury B	Injury C
1	0.499397455	0.83344946	0.89570264
2	0.283490891	0.13136275	0.08442464
3	0.169703456	0.03165187	0.01884134
4	0.029519078	0.00281009	0.00080061
5	0.01788912	0.00072584	0.00023077
	1	1	1

Factors from Table F-1 are multiplied by the comprehensive and economic costs reported by Blicoe (1996) based on MAIS category, to generate the converted ABC fatality and injury costs. Blincoe costs are listed in Table F-3, and converted ABC costs are listed in Tables F-4 (comprehensive) and Table F-5 (economic).

Table F-3 Comprehensive and Economic costs by MAIS Injury Category

Injury Class	Economic Costs	Social Cost
MAIS 1	3,980	7,577
MAIS 2	31,367	130,344
MAIS 3	98,214	466,519
MAIS 4	221,696	1,185,514
MAIS 5	697,736	2,501,292

Source: Blincoe (1996)

Table F-4 Converted ABC Fatality and Injury Costs--1994 dollar value-Social Costs (Comprehensive)

	Injury A	Injury B	Injury C
MAIS1	\$3,783.93	\$6,315.05	\$6,786.74
MAIS2	\$36,951.34	\$17,122.35	\$11,004.24
MAIS3	\$79,169.89	\$14,766.20	\$8,789.84
MAIS4	\$34,995.28	\$3,331.40	\$949.14
MAIS5	\$44,745.91	\$1,815.53	\$577.23
Total	\$199,646.35	\$43,350.52	\$28,107.20

Table F-5 Converted ABC Fatality and Injury Costs-1994 dollar value-Economic Costs

MAIS	Injury A	Injury B	Injury C
MAIS1	\$1,987.60	\$3,317.13	\$3,564.90
MAIS2	\$8,892.26	\$4,120.46	\$2,648.15
MAIS3	\$16,667.26	\$3,108.66	\$1,850.48
MAIS4	\$6,544.26	\$622.99	\$177.49
MAIS5	\$12,481.88	\$506.44	\$161.02
Total	\$46,573.26	\$11,675.67	\$8,402.04

APPENDIX G
SPREADSHEET SAMPLES OF BRIDGE ACCIDENT EVALUATION

1-Bridge Related Accident Cost Spreadsheet Samples

(KABCO)- K= Fatality, A= Injury A, B= Injury B, C= Injury C, O= Property Damage Only

The total average cost is calculated according Equation 23.

$$ABAC = (3{,}014{,}525.0 * K + 211{,}515.4 * A + 45{,}927.2 * B + 29{,}844.7 * C + PDO) * AF \quad (23)$$

The numerical value for each KABCO injury type is the number of injuries recorded in the data base. AF is the number of allocations recorded in the database. Below are five examples with different allocation factors and different situations.

Case 1:
Table G-1. One Accident Occurred to Just One Bridge

ST BR #	Alloc	K	A	B	C	O ($)	Accident Cost ($)
940098	1	0	1	0	0	3,000	214,515

Case 2:
Table G-2. One Accident Allocated to Two Bridges

ST BR #	Alloc	K	A	B	C	O ($)	Accident Cost ($)
930414	0.5	0	0	2	0	800	49,865
940140	0.5	0	0	0	0	11,500	5,750

It is not possible to match the two bridges involved in the accident using the spreadsheet. In order to match the two bridges involved in the accident it is necessary to check the original police report for the accident.

Case 3:
Table G-3. One Accident Allocated to Three Bridges

ST BR #	Alloc	K	A	B	C	O ($)	Accident Cost ($)
870727	0.3333	0	0	0	0	7,600	2,533
870694	0.3333	0	0	0	0	900	300
870357	0.0333	0	0	0	0	10,200	2,400

Case 4:
Table G-4. One Accident Allocated to Four Bridges

ST BR #	Alloc	K	A	B	C	O ($)	Accident Cost ($)
930262	0.25	0	0	0	0	800	200
930261	0.25	0	0	0	0	5,000	1,250
930256	0.25	0	0	0	1	7,000	10,069
930254	0.25	0	0	0	1	7,000	10,069

Case 5:
Table G-5. One Bridge With Several Accidents in a Year

ST BR #	Alloc	K	A	B	C	O ($)	Accident Cost ($)
150094	0.5	0	0	0	12	39300	219,300
150094	0.5	0	0	1	0	3000	26,233
150094	0.5	0	0	1	0	400	24,933
150094	0.5	0	0	0	1	5700	19,488
150094	0.5	0	0	0	0	900	450
150094	0.5	0	0	0	0	900	450
150094	0.5	0	0	0	0	800	400
150094	0.5	0	0	0	0	200	100

APPENDIX H

VOC EVALUATION FOR CARS, VANS AND LIGHT TRUCKS

1.Background

In 1991 the Federal Highway Administration published , a study about operating costs for automobiles, vans and light trucks (FHWA 1991). The study assumes that each vehicle will run 12,900 miles per year during a lifetime of 12 years. They use as operating cost parameters fuel, oil, tire, maintenance, parking & tolls and associated taxes. The cost per mile average for each vehicle category is reported in Table 19. They are adjusted to 1998 by the index of 1.203. This index was generated using the Consumer Price Index –all items, by the following escalation factor:

Escalation Factor = 163.9 (Dec.98) / 136.2 (Dec.91). = 1.203 (Dec.1998).

Table H-1. Adjusted Operating Costs for Automobiles, Vans, and Light Trucks--Cost Per Mile (1998 dollars)

Size	Fuel & oil	Tires	Maintenance	tools	Total Cents/Mile
Subcompact	5.7	0.84	4.81	0.13	11.52
Compact	6.5	1.08	4.69	0.13	12.37
Intermediate	7.5	1.2	5.05	0.13	13.93
Full Size Car	8.1	1.2	5.41	0.13	14.89
Compact Pickup	6.8	1.2	4.81	0.13	12.96
Full size Pickup	10.22	1.44	5.17	0.13	16.93
Minivan	8.42	1.32	4.81	0.13	14.65
Full Size Van	13.35	1.68	5.05	0.13	20.18

Source: Cost of Owning & Operating Automobiles, Vans & Light Trucks- USDOT 1991

2.0 Fuel and Oil

Fuel and oil was calculated using the following factors: for fuel the price of $1.196 per gallon of gasoline, including taxes. The average gasoline mileage used for each vehicle classification was the following: subcompacts 26.23 mpg, compacts 22.28mpg, intermediates 19.87, full-size cars 17.99 mpg, compact pickups 21.69 mpg, minivans 17.54 mpg, full-size vans 11.23 mpg.

For oil expenses, the criterion used is one oil change every 7,500 miles. One extra quart of oil is assumed between changes. The average capacity used was 4.7 quarts for subcompact cars and compact pickups; 5.5 quarts for full-size pickups and full-size vans; and 5.0 quarts for all other vehicles.

3.0 Tires

For tires it was assumed that twelve new radial tires will be purchased during the life of the vehicle. The number of replacement tires is based on a life expectancy of 40,000 miles for radial tires.

4.0 Repair & Maintenance

For repairs and maintenance, the criterion used was to subdivide scheduled and non-scheduled maintenance types. Scheduled maintenance is maintenance specified in the owner's manual, and assumed to be performed by professional mechanics. Unscheduled maintenance was reported by taking data on total costs for repair and maintenance from the 1989 Consumer Expenditure Survey, adjusting for differences across vehicle classes and subtracting the cost of scheduled repair and maintenance. The estimated costs exclude the costs of any repairs that are done by a dealer when a vehicle is traded, but that would have

to be performed by the owner if the vehicle is kept for 12 years. About 65% of repair and maintenance costs are for labor and 35% are for parts. A Baltimore, Maryland labor rate of $48.67 per hour was used.

5.0 Parking and Tolls

Parking and tolls include an average of 1.19 cents per mile for parking and 0.09 cents for toll charges for using private or public highways, tunnels and bridges. The toll charges are considered in the VOC evaluation costs, however, parking charges were not.

6.0 Average VOC for Cars

The average value for all car sizes listed in Table 19 results in a value of 13.17 cents per mile. Averaging pickups and vans the resulted value is 16.18 cents per mile. For the objective of this study the average composite value for cars will be used for the category of cars, and the average composite value for vans and pick-ups (light trucks) will be considered under the classification of four-tire truck. These average costs, converted into cents-per-kilometer, are listed in Table 20.

Table H-2 Operating Costs-Per-Kilometer for Cars and 4-Tires Trucks

Vehicle type	Cents per kilometer
Cars	8.23
Four Tires Trucks	10.11

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BIOGRAPHICAL SKETCH

My biographical sketch can be divided into two phases. Phase one covers 15 years of experience working in the construction and management of new investments on a total of over $200 million. Phase two covers the next 15 years working as a consultant and assistant professor at the Federal Universities in Brazil and as a graduate student here in the United States.

For part one, refer to the publication Article " Loma Linda University's New MBA Program", Inland Empire Magazine, Volume 8 / Number 8, Riverside, CA, August 1983, pp. 103-104, presented below. For part two, below is a summary of the main activities and achievements.

"... Roberto Soares earned a degree in chemical engineering from Brazil University in Rio de Janeiro. As he worked for such companies as Atlantic Richfield and American Cyanamid he found himself supervising projects totaling nearly $200 million.

... Soares says he "studied to be a chemical engineer, but in the years since I graduated with the degree, I have coordinated three big projects. A Japanese firm hired me as the project coordinator for a $100 million investment in a plant that produced low density polyethylene."

"American Cyanamid hired me as project coordinator for a $40 million plant that produced complex malathione, and Atlantic Richfield employed me to coordinate the development of a plant that produced Duotreat, white oils."

In the capacity of project coordinator, Soares oversaw the projects from the feasibility and engineering studies through the construction and start-up phases. He also saw to it that the product was produced to specifications.

"As I did all this work, I realized that I was contracting engineers and managing the plants--all business functions. Thus, I decided to polish my knowledge by taking an MBA course. . . . I think that my combination of business and engineering will enable me to work any place in the world."

Coming to the United States for his degree has cost Soares about $40,000. " I sold all my personal assets in order to come here to study. Some of my friends asked me why. I simply told them that I was exchanging them for a flexible asset in my mind-education."

After the conclusion of my MBA, I started in academia as an assistant professor at Federal Universities of Maceio and Rio de Janeiro in Brazil, teaching at the undergraduate and graduate level disciplines in engineering, management and finance. In the early 90s I started research to create a model to manage the construction of affordable housings, that resulted in a Doctor of Science degree by the Federal University of Rio de Janeiro. I also conducted research to transform industrial waste as a raw material for the construction industry. In the middle 90s I decided to move definitively to the United States, and then I started research about user costs in Bridge Management Systems that resulted in this dissertation that is a partial fulfillment of the Ph.D. degree at the University of Florida. As a graduate student, I received an Eisenhower Fellowship grant for research, which allowed me to conclude my research, giving more experience in transportation related issues. My plans are to continue in academia as a professor and researcher.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Fazil T. Najafi, Chairman
Associate Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ramesh L. Shrestha
Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Paul Y. Thompson
Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Charles R. Glagola
Assistant Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Sebastian L Foti
Assistant Professor of Instruction and Curriculum

This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1999

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